THE COORDINATE TRANSFORMATION METHOD OF HIGH RESOLUTION DEM DATA

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ABSTRACT:

Coordinate transformation methods of DEM data can be divided into two categories. One reconstruct based on original vector elevation data. The other transforms DEM data blocks by transforming parameters. But the former doesn’t work in the absence of original vector data, and the later may cause errors at joint places between adjoining blocks of high resolution DEM data. In view of this problem, a method dealing with high resolution DEM data coordinate transformation is proposed. The method transforms DEM data into discrete vector elevation points, and then adjusts positions of points by bi-linear interpolation respectively. Finally, a TIN is generated by transformed points, and the new DEM data in target coordinate system is reconstructed based on TIN. An algorithm which can find blocks and transform automatically is given in this paper. The method is tested in different terrains and proved to be feasible and valid.

1. INTRODUCTION

With the development of geographic coordinate systems, different coordinate systems are used in different periods and areas. For instance, there are 3 kinds of coordinate systems used in China, which are Beijing 54, Xian 80 and CGCS2000 coordinate systems (Chen, 2008; Dang et al., 2006). Correspondingly, spatial data’s coordinate systems are not consistent in different periods. However, accompanying applications of multiple resources of spatial data, the inconsistent coordinate system problem leads to a serious data gap in spatial data application and sharing. Therefore, the coordinate transformation is inevitable.

DEM (Digital Elevation Model) data is a kind of important spatial data in GIS, which is a digital model and 3D presentation of terrain surface. DEM is established based on data collection of spatial entities and interpolation of collected data (Li and Zhu, 2003; Li et al., 2005), is also the common form for collection, storage and analysis of topographic data (Burrough, 1986; Weibel and Heller, 1991; Carter, 1988). Usually, the transformation of DEM data coordinate system is not complex. If the original collecting vector data or point cloud data exist, the transformation is just the process of DEM reproduction. However, in reality, we always meet the problem that reproduction is impossible due to the original data absence. In the case of original data absence, the transformation of DEM coordinate system is different from the transformation of spatial vector data and spatial image data. Image transformation method is also infeasible in high resolution DEM data transformation because it may cause deviation jump in the transforming process, especially at the joint place between blocks using the different parameters. Existing methods of coordinate transformation are always dealing with small scale DEM data transformation, which can’t be used to transform high resolution DEM due to the low accuracy. In addition, the error of high resolution DEM data coordinate transformation is not very clear.

Considering the regular grid model is more common in DEM data formats (Lu et al., 2002), and the error control is challengeable in high resolution DEM coordinate transformation, a method of high resolution regular grid DEM data coordinate transformation is mainly explored in this paper. The paper is organized as follows. Section II proposes a high resolution DEM data coordinate transformation model. Section III describes the algorithm and experimental analysis of the model. Conclusion is presented in section IV.

2. COORDINATE TRANSFORMATION MODEL OF HIGH RESOLUTION DEM DATA

2.1 Basic Principles

The process of high resolution DEM data coordinate transformation is illustrated as Figure 1. Figure 1a is the original regular grid DEM in source coordinate system, named source DEM. Figure 1b is the discrete elevation points corresponding to grid cells in Figure 1a. Figure 1c is the points after coordinate transformation. Figure 1d is the Delaunay triangulation of points in Figure 1c. Figure 1e is the TIN after rendering, and Figure 1f is the final DEM in target coordinate system, named target DEM. The main steps include discretization, coordinate transformation, TIN generation, and target DEM generation.

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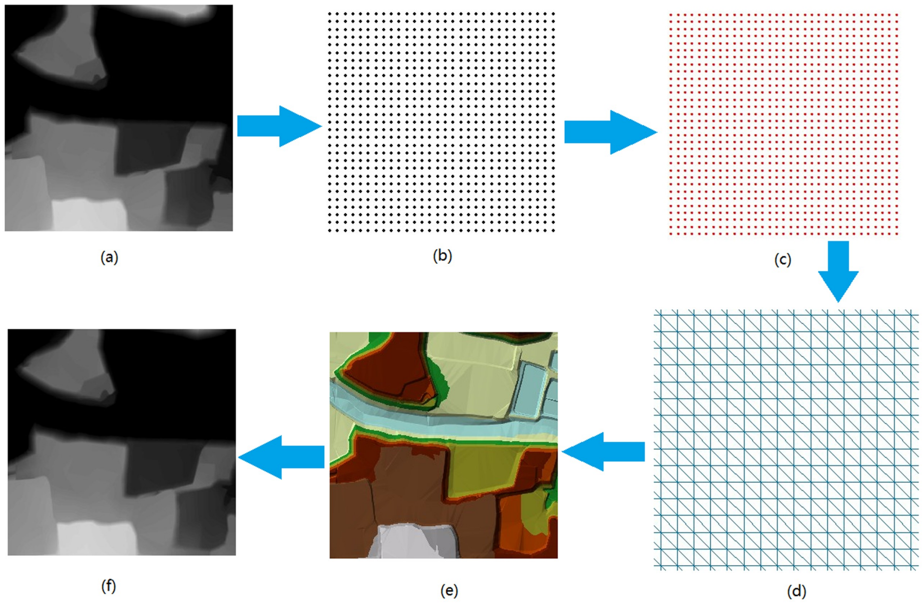

Figure 1. The process of large scale DEM data coordinate transformation. (a) Source DEM; (b) Discrete elevation points (c) Elevation points after adjustment; (d) Delaunay triangulation; (e) TIN after rendering ; (f) Target DEM.

2.2 Discretization and Transformation

Regular grid DEM is an elevation model composed by the limited grid sampling points, and it approximately simulates actual ground (Tang et al., 2006). In other words, a value of a regular grid in DEM can be approximately regarded as the elevation of the regular grid covering the region. In the high resolution DEM, an area of a grid covering is smaller. Therefore, a regular grid in DEM can be replaced with the discrete vector points. The coordinates of points are the regular grid centre coordinates, and point values are the grids' elevation. In this simulation method, DEM is converted into discrete vector set of points, and each point in set corresponds to each regular grid in source DEM. Then the simulation vector elevation data are transformed into new coordinate system (target coordinate system) according to the algorithm in section 3.1. In order to avoid gap errors at the edges of neighbour blocks, the transform needs parameters (4 parameters or 7 parameters) on four corner points of every DEM data blocks, and corner point parameters should be calculated into (Δx, Δy) form.

2.3 Generation of TIN by Discrete Vector Points

There are some ways to simulate elevation by vector data, including irregular triangulated network, and regular square grid etc. Irregular triangulated network and regular square grid both are widely applied for data structure of digital representation for continuous surface. Compared with the square grid, TIN has two advantages as follows (Li & Zhou 2003):

- Comparison between TIN and square grid both generated by the same points, TIN has smaller root mean square error under the circumstances of same amount of data.
- The quality of the square grid declines faster than that of TIN when number of sampling points decreases.

After coordinate transformation, the even distribution of discrete vector points becomes uneven. The uneven distribution is not suitable for grid data based DEM establishment method (Lu et al., 2002). Therefore, discrete vector coordinates are transformed, and TIN is generated by discrete vector points according to the method of Delaunay triangulation establishment. A linear interpolation is used here, which is considered as a safe interpolation technique with only minor unrealistic surface features (Carrara et al., 1997).

2.4 Re-sampling TIN and Generation of DEM

According to the requirements for DEM frame, DEM in target coordinate system is generated by the means of interpolation and re-sampling based on TIN. This method is better than discretization or interpolation in accuracy and efficiency. At the same time, it can flexibly adapt to the data of complex terrain because of full consideration of the characteristics of the data. In the high resolution DEMs, slope error is smaller by this method (Carter, 1992).

3. ALGORITHM AND EXPERIMENTAL ANALYSIS

3.1 Algorithm

The algorithm's mechanism of high resolution DEM data coordinate transformation model based on TIN is complicated, which includes DEM discretization and vectorization, bilinear interpolation coordinate transformation, Delaunay triangulation generation and transformation from TIN to regular grid. The flow of the algorithm is shown as Figure 2, and the details of the algorithm are described as follows:

1. Parameter calculations of block corners. The scope of target DEM block is different from source block scope. First step is to divide DEM blocks in target coordinate system. Second step is calculate transformation parameters of corresponding corner points corresponding

with all blocks, including source DEM blocks and target DEM blocks. Seven parameters calculation (with Bursa model) is suitable for enough known points distributed around. It also can be calculated with interpolation based on known transformation parameters around. Corner point parameters should be calculated into (Δx, Δy) form. Figure 3 is the illustration of block divisions and transformation parameters of source and target DEM. Figure 3c is the relative position corresponding to source and target blocks. (Δx, Δy) are parameters from source to target coordinate transformation. Contrarily, (Δx',Δy') are the parameters from target to source.

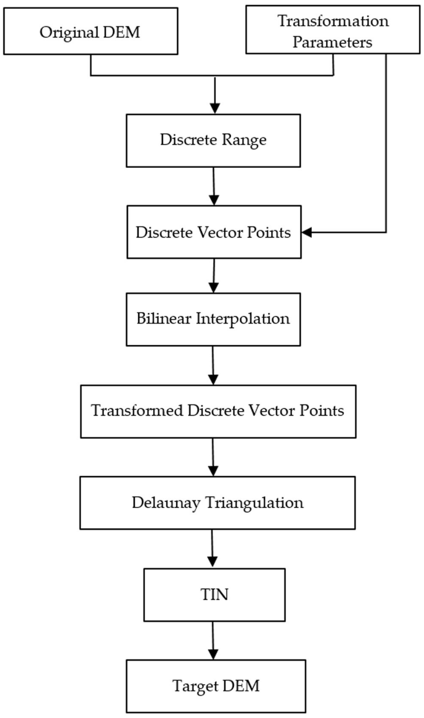

Figure 2. The algorithm flow of high resolution DEM data coordinate system transformation.

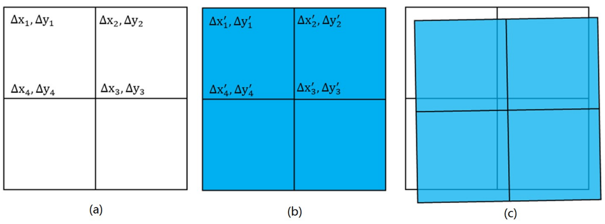

Figure 3. The block divisions and transformation parameters of source and target DEM. (a) Source DEM blocks; (b) Target DEM blocks; (3) Relative position.

2. Calculation of discretization range. Discretization range(X, Y) is the frame extended 10 regular grids. This method could simplify DEMs' splicing and reduce the calculation, so efficiency of calculation is improved. The range calculations are as formulation (1-6). x_i' and y_i' in equations are block corner coordinates in target DEM coordinate system. $\Delta x_i'$ and $\Delta y_i'$ are transformation parameters corresponding to the target block corner points. D is the length of regular grid. The Figure 4 is the calculation of discretization range. The orange rectangle in Figure 4b is the target block range expanded with 10 grids length in four boundaries, and the red rectangle in Figure 4a is the discretization rang of source DEM corresponding to the target block range.

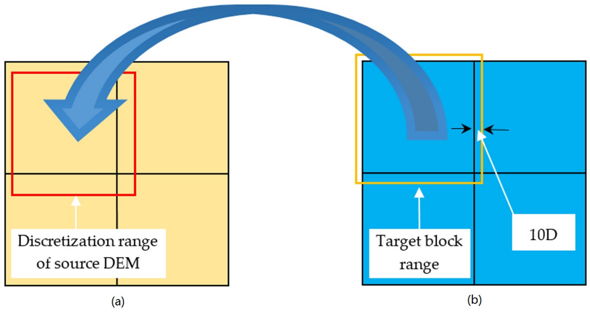

Figure 4. The calculation of discretization range. (a) Discretization range of source DEM; (b) Target block range.

$$x_{\min} = \min\{x_i' - \Delta x_i' - 10D\} \quad (i = 1,2,3,4) \tag{1}$$

$$x_{\max} = \max\{x_i' - \Delta x_i' + 10D\} \quad (i = 1,2,3,4) \tag{2}$$

$$y_{\min} = \min\{y_i' - \Delta y_i' - 10D\} \quad (i = 1,2,3,4) \tag{3}$$

$$y_{\max} = \max\{y_i' - \Delta y_i' + 10D\} \quad (i = 1,2,3,4) \tag{4}$$

$$X = \{x_{\min} \le x \le x_{\max}\} \tag{5}$$

$$Y = \{y_{\min} \le y \le y_{\max}\} \tag{6}$$

3. Vectorization of discrete points. In the discretization range, the value and centre coordinates of regular grid are read and DEM is converted to discrete vector elevation points. In the process of vectorization, appropriate extra points outside DEM frame can guarantee the quality of TIN and the enough scope covering target block frame, also guarantee the good effect in DEM block joint.

4. Coordinate transformation. Considering that the data volume of discrete vector points is too huge, therefore, the method of bilinear interpolation in this step is adopted instead of the method of point-by-point to calculate the transformation parameters. According to the transformation parameters of the DEM block corners, transformation parameters of each discrete point's coordinate are calculated by bilinear interpolation. The transformation parameters (Δx_p, Δy_p) at different grids are computed by formula (7). In this equation, (x_1, y_1), (x_1, y_2), (x_2, y_1), (x_2, y_2) are coordinates of DEM block corners, (Δx_1, Δy_1), (Δx_2, Δy_2), (Δx_3, Δy_3), (Δx_4,Δy_4) are transformation parameters of DEM corners.

$$\begin{cases} \Delta x_p = \dfrac{\Delta x_1}{(x_2 - x_1)(y_2 - y_1)}(x_2 - x)(y_2 - y) + \dfrac{\Delta x_2}{(x_2 - x_1)(y_2 - y_1)}(x - x_1)(y_2 - y) \\ + \dfrac{\Delta x_3}{(x_2 - x_1)(y_2 - y_1)}(x_2 - x)(y - y_1) + \dfrac{\Delta x_4}{(x_2 - x_1)(y_2 - y_1)}(x - x_1)(y - y_1) \\ \Delta y_p = \dfrac{\Delta y_1}{(x_2 - x_1)(y_2 - y_1)}(x_2 - x)(y_2 - y) + \dfrac{\Delta y_2}{(x_2 - x_1)(y_2 - y_1)}(x - x_1)(y_2 - y) \\ + \dfrac{\Delta y_3}{(x_2 - x_1)(y_2 - y_1)}(x_2 - x)(y - y_1) + \dfrac{\Delta y_4}{(x_2 - x_1)(y_2 - y_1)}(x - x_1)(y - y_1) \end{cases} \tag{7}$$

5. Generation of Delaunay Triangulation. Delaunay triangulation is established by the transformed discrete vector points.

6. TIN Generation. TIN is generated based on the Delaunay triangulation (Zhou et al., 2005).

7. DEM Generation. TIN is converted into the regular grid DEM, according to the rules in the target coordinate system.

In order to verify the feasibility and validity of the method, Visual studio 2005 C# is adopted as tools under Windows. The file of discrete vector points is in SHP format. That is, the file is written in SHP storage format by binary stream instead of API provided by ArcGIS. Generation of TIN by discrete vector points was adopted in the algorithm, with TIN being calculated by API based on ArcGIS. The efficiency of system operation could be greatly improved in these methods.

3.2 Experimental Results and Analysis

The data accuracy of transformed DEM, using high resolution DEM data coordinate transformation model, is compared and analyzed. Elevation data in DWG format are selected to experiment as the original standard data, which include mountain, plain and valley. The transformation of coordinate was done based on these DWG data and generated regular grid DEMs respectively with 1:1000 scale (1 m grid size) and 1:500 scale (0.5 m grid size), named A DEM data. The transformed DEM data are generated with high resolution DEM data coordinate transformation model (named B DEM). Then compare the errors between A DEM and B DEM, and the flow of experimental analysis is shown as Figure 5.

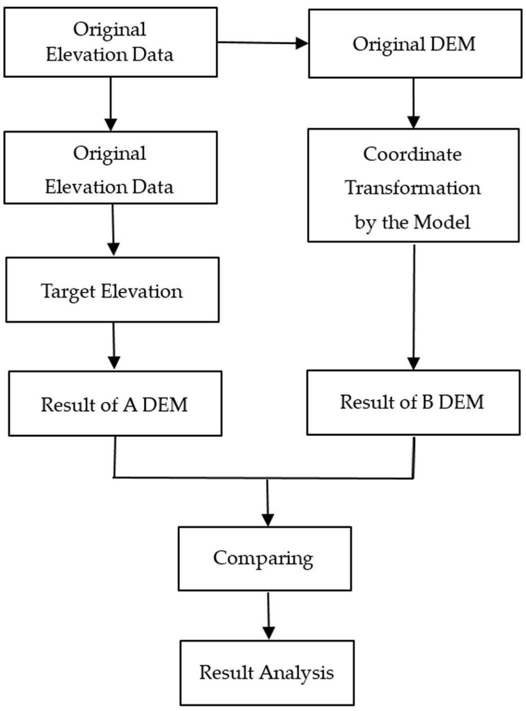

Figure 5. The flow of experimental analysis.

Two methods from the articles (Qi et al., 2011; Wechsler and Kroll, 2006; Oksanen and Sarikosi, 2005) were used to check errors. One is error comparison between grid elevations and point elevations. 610 elevation points of the original elevation data were selected. Selected points were compared with the corresponding coordinates in result B DEM. The max error and mean error were computed. In addition, the grid value of result A is compared with corresponding grid values in result B. The max error and mean error also were computed. The comparing results are listed in Table 1.

Scale	1:500	1:1000
Max error of elevation point (m)	0.294	0.255
Mean error of elevation point (m)	0.001	0.001
Max error of grid (m)	0.139	0.140
Mean error of grid (m)	0.001	0.001

Table 1. DEM elevation comparison.

The other one is comparison between contours. The contours generated by result A DEM were compared with original contours. The Figure 6 is the illustration of the comparison between contours, red lines are original contours, and blue lines are contours generated by result B DEM. The maximum average distance between two lines is about 0.04 m.

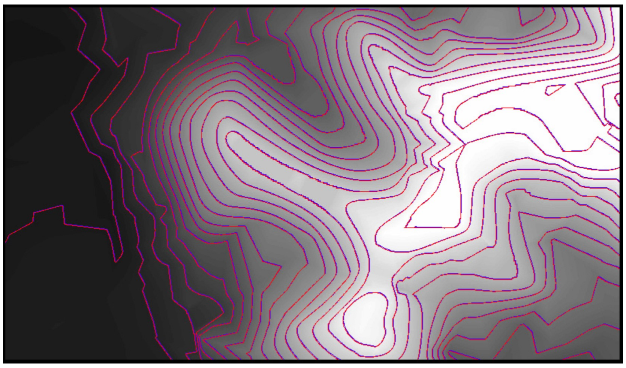

Figure 6. The comparison between contours

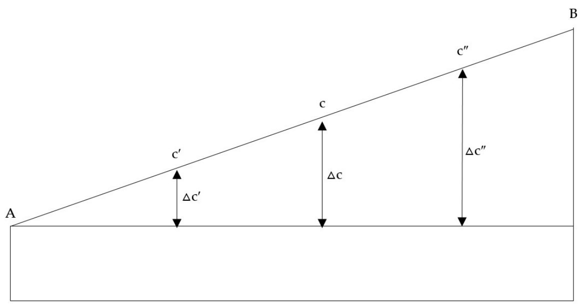

Figure 7. The error of resampling elevation

Based on the experiment, it proved that the source of DEM coordinate conversion error mainly comes from the error of resampling elevation. The resampling error is illustrated in Figure 7. Point A and B in Figure 7 correspond to two adjacent grid centres, and AB line is the slope after fitting. c, c' and c'' are possible resampling positions, and Δc, Δc' and Δc'' are resampling errors in elevation corresponding with c, c' and c'' positions. Obviously, the elevation resampling error is mainly affected by the terrain slope and the panning quantity of coordinate transformation. A further experiment have been done to check the effect of slope and panning quantity. The experiment select 400 points uniformly in a 1:1000 standard DEM block and calculate the mean elevation errors before and after transformation based on slope and panning quantity classification (9 panning quantities are used, i.e. 0.1 to 0.9 grid cell length with 0.1 interval). Statistical data are shown in Table 2, and the corresponding statistics chart is shown in Figure 8.

Panning (grid cell) Slope(Degree)	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
0-10	0.0032	0.0065	0.0102	0.0145	0.0175	0.0106	0.0079	0.0053	0.0027
10-20	0.0320	0.0639	0.0815	0.1056	0.1308	0.1002	0.0752	0.0505	0.0258
20-30	0.0273	0.0546	0.0749	0.0913	0.1898	0.1539	0.1213	0.0819	0.0392
30-40	0.0739	0.1478	0.2177	0.2856	0.3527	0.3060	0.2266	0.1500	0.0748
40-50	0.0768	0.1535	0.2329	0.3136	0.3938	0.3448	0.2405	0.1739	0.0859
50-60	0.1008	0.2017	0.3152	0.4356	0.5531	0.4014	0.3138	0.2134	0.1062

Table 2. Statistical results in different slope and panning quantity.

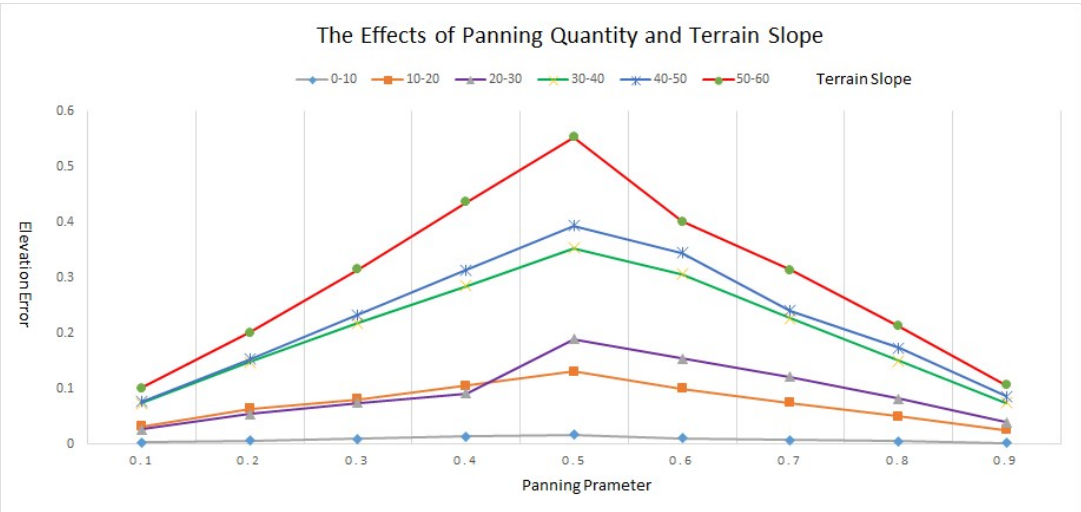

Figure 8. The statistics chart corresponding with Table 2

From the experiment we find that that, in the steep areas, the transformation error increases with the increasing of slope. Elevation error is also influenced by the panning quantity of the transformation. When the panning quantity is close to 0.5 times grid cell length (e.g. Δx_p=xx.492m, grid cell length is 1m), the elevation error reaches maximum. On the contrary, panning quantity approaches to integer length of grid cell, and the impact is very small. The experimental results prove that the method is feasible if the terrain is not very deep and the panning quantity is not close to 0.5 times grid cell length.

4. CONCLUSION

Coordinate transformation of DEM is often encountered in practice. Although the reconstruction based on original elevation data is accurate and reliable, it isn't adopted in the absence of original data. The method of image data transformation may lead to obvious error at joint place between adjoining DEM blocks, especially in high resolution DEM data transformation. A coordinate transformation method towards high resolution DEM data is proposed in this paper. Firstly, regular grid DEM is discretized into vector points. Secondly, the vector points are transformed respectively with vector transformation method. Thirdly, TIN based on transformed points will be generated. Finally, new DEM based on TIN is constructed. Considering huge DEM data and blocks in many cases, an algorithm of automatic transformation is given in this paper. The software has been developed and the experimental results find two factors mainly affecting the transformation accuracy. One is slope of terrain and the other is panning quantity. The steeper the slop, the greater the transformation error. When the panning quantity is close to integer and half grid length the elevation error reaches maximum. Contrarily, the impact is very small when panning quantity approaches to integer length of grid cell. The experiments prove that the method is feasible for high resolution DEM transformation in general situation. It is worth noticing that the error is larger in steep area or 0.5 times panning quantity of grid length.

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