Designing Thought, Technical Line and Some Theoretical Issues on Geospatial Digital Framework of China

HU Peng  HU Yuju  YANG Chuanyong  WU Yanlan  HU Hai

1 Introduction

A designing issue for China’s geospatial digital framework has been put forward in Reference [1]. This issue is of great importance and will exert a tremendous influence which affects the nation’s whole construction problem of geospatial digital products. This is of very important basic significance for our geographic information science and production work. “More considerations will benefit the tailor”. For the convenience of discussion, let the above issue be called “the framework”.

2 The technical line for the construction of large scale GIS

The scale system of China’s basic geographic information is established in accordance with its basic topographic map system, while the basic scale system is 1:1 000 000, 1:500 000, 1:250 000, 1:100 000, 1:50 000 and 1:10 000. Among them, the 1:1 000 000 map is of international standard sheet and uses the unified conformal conical projection (the Lambert Projection). And all maps at 1:500 000 to 1:10 000 use the Gauss-Krüger projection. For these maps, the 1:10 000 one uses three degree zone, while the maps of other scale use six degree zone. Considering application, common interest of information, economy of expense and efficiency, the following four scales are taken as the basic resolutions for China’s present standard of geographic information, which are 1:1 000 000, 1:250 000, 1:50 000 and 1:10 000.
2.1 Discussion on the construction and maintenance

A large foundational project should be based on sustainable development. There are two modes in producing basic geographic information, i.e., the vector mode and the mode of the combination of vector and raster. The production of the basic geographic information at the resolution of 1:1,000,000 and 1:250,000 was fulfilled by the vector mode. For the former scale there are about 80 sheets, and for the latter about 800 sheets. Much manpower and material has been spent to produce both of them. And it is almost impossible to produce a large number of sheets at the resolution of 1:50,000 and 1:10,000 by using the vector mode. As introduced in Reference [1]. Taking the example in Guangdong, there are more than 6,500 sheets of topographical maps at the scale of 1:10,000 to cover the whole 178,000 km² of the province. If the vectorization of the whole elements needs 0.2 manpower per year for a sheet, then the total expense will be 1,300 manpower per year, that is to say, this needs 130 workers to work ten years. This is only for the stage of data collection. As to the maintenance and updating stage, GIS experts consider that the new data input will be more convenient than revisional input if the GIS entity updating reaches over 10%, and the situation of new database will be better as well. Taking the map of Beijing as an example, its data are equal to 1:20,000-1:50,000 and its updating speed is an edition once a month. For the stressed area, the change is taking place at an even more rapid speed. Such contradiction makes the maintenance of geographic information established by the vector mode very difficult. The practical situation proves that all the large scale GISs are facing the difficulty of their maintenance.

Though the U.S. started the construction of the database for 1:24,000 digital line graph more than ten years ago, there are still a large number of maps which cannot be digitized and input into the database[1]. It is clear that we cannot go in the same way.

Compared with vector digitization, scanning digitization is quicker many times. Therefore, the combination of raster and vector is relatively reasonable.

2.2 The way and level of information application decides the information form

In comparison with the former problem, application is a more important one, because it is the aim while construction is just a means and tool.

The essential aim of the framework of geospatial data is to integrate and share geospatial information, i.e., geographic information.

The basic geographic information itself is the very important information for the national administration, planning and construction in different fields. Besides, based on it information from different industries and circles can be integrated together for wider application.

The smallest element of GIS is an entity, which has attribute data and spatial data. For the basic geographic information, only 95% entities have their spatial data, while their attribute data are short. Generally, there is only a category data or classification data, or at most there is a name or numerical annotation. This situation is quite different from specialized data. The spatial data of the entities of basic geographic information are those figures, sizes, directions, and categories, i.e., those points, lines, areas and colours. All of them can be seen on the maps. But people may think:

1) Graphic data and its changed numerical data have different forms, but the essences are the same. It is clear that such expense sometimes is necessary and sometimes not.

2) As all practical uses are concrete and limited, people neither can make the product suitable for all purposes, nor can produce it in time and perfectly. Therefore, transformation should be aimed at the application and the concrete situation, in other words, only transforming the necessary part is enough. This part is the attribute part or the spatial part.

3) The transformation needs to be done for what is to be applied. If it is not in use, it should not be transformed. This is just the temporal part.

For the above three layers of filtering, what is the
necessary suitable percentages? Plenty of resources will be wasted, if we do not consider the three percentages well. A fine technological line should properly make the above three filterings.

Though the vector digitization keeps many advantages, it takes a long time to produce the necessary result. And due to its characteristics, the specialities of maker and user are different from each other, which causes big difficulty to adequately exercise the above three filterings in time.

For example, the vector digitization can be done only by taking a sheet as a unit, neither for general vectorization nor for scanning vectorization. Once a sheet is done and leave the plate, it will be a great difficult to supplement something. That is, digitization should be done in a time interval. As workers do not understand the needs of users and the work requires a rather long time, the natural selection for the digitization is that it should be done as much detail as possible in a time.

From the viewpoint of application, the vector method is not so nimble. It cannot be easily used and it often causes waste of resources, while the combination of vector and raster method is much nimble and convenient. We are going to discuss it later.

From the analysis of the two sides, although vector method keeps its advantage of mature and clarity, for the large scale GIS, its weak point is rather clear.

Reference [1] introduces that since 1994 the US has carried out its database construction plan for digital geospatial data framework, which is mainly based on digital orthophoto image, and that, at the same time, it produces digital terrain model, besides, the geodetic control points and vector data of transportation lines, water system, administration boundaries and cadastral lines are added.

The viewpoint of the combination of vector and raster method in Reference [1] is very important and quite correct. From the basic viewpoint of constructing national geographic information, the combination of vector and raster method is a sound way.

3 The practical aim of construction of digital geospatial data framework and demands for it

The discussion of this issue is of fundamental meaning. It decides the whole designing and technical line and the whole technical plan and method as well. Its aim is to satisfy the urgent and wide needs for geographic information from all industries. At present, the aims from the following two aspects are prominent.

1) Construction of national and provincial basic GIS. It is mainly used for browse and examination, understanding, measuring and analysis of the geographic situation, making large and medium scale planning, strategic and even tactical decision. At the same time, it is the original system for establishing various spatial systems. At any time, different spatial information can be added to it and it becomes various national and provincial spatial systems, and can be used for planning and decision-making of various specialities. It can also be widened to the neighbour area and connected with other regions. In the meantime, it also needs to fit the change with time and to show the history and development of the area.

2) To satisfy the needs of the traditional analog product, the map demanded by the society. The needs of up-to-date property and the number of maps are increasing. These should be noted during the design of the framework. And the most important point is that people can conveniently use the tools in framework, remote sensing and GPS to maintain and renew the analog product, and to produce various up-to-date maps which resemble modern maps.

3) The basic technical demands for the framework From the above two aspects, it is easy to know that the framework should satisfy the following demands:

① The contents, time and space can be widened and easily done.
② Spatial multi-resolutions
No matter how the science and technology develops, the fact that people receive information main-
ly through vision is not changed. The demand for information is not the more the better, nor is it on the contrary. Their demand for information density is of multi-resolution, which should suit the various aims of applications. The suitable resolution has not brought attention to in the past yet. Here we would like to define that an absolute resolution for entities is the expressed number of entities per square meter or absolute resolution of characteristic points. The latter is expressed by the mean entities' characteristic point number per square meter.

The mean entity number per square centimeter on the visual plane, or the characteristic point number per square centimeter on the visual plane is called the relative characteristic point resolution. The latter expressed on the map is the map loading measure. The suitable map loading measure is always the main topic of map design and map study. The relative resolution for the paper map has been studied fully, while that for the electronic map has not been studied yet. Roughly, it can be used temporarily. In the situation of electronic maps, though the image can be moved to the center, and different computer graphic means that twinkling, change of color, animation and so on can be used so that the object concerned can be shown prominently. Meanwhile, the information density contained in the electronic map is actually without limitation, however, the problem what relative resolution will be the most suitable one for the screen map has not been solved yet. And this is and perhaps will be an important research topic of geoinformation science.

Because at present the basic point on the screen is of about 0.20 mm—0.30 mm, which can substitute for 0.1 mm resolution on the paper maps in traditional cartography. This is the smallest basic size for visualization on paper maps and on screen.

Because the kinetic compilation, the online map compilation technique, has not been mature yet, directly establishing multi-resolution geographic basic information by using maps at several scales is reasonable at present stage.

3 The correctness of measuring

The analysis of spatial measurement is the basis of all spatial analyses, and its precision is the precision basis of spatial analysis and decisionmaking.

The practical three-dimensional geographical space is affected by different factors, which is actually a four-dimensional or multi-dimensional space. The incorrect measurement of two and three-dimensional spaces will basically affects the standardization and correctness of data integration at four-dimensional and multi-dimensional spatial data integration, and affects the correctness and standardization of data analysis. Finally it will affect the whole geographic information framework.

4 The spatial mathematical basis for data framework

At present, the upsurge and development of GIS of distributed mode, digital earth and digital areal conception has put forward urgent demands to the construction and application of the framework. These demands are guaranteed actually by its mathematical basis. No matter what kind of spatial mathematical basis the framework or its contents have taken, it is always the most important basic issue that should be noted. The essence of so-called spatial mathematical basis of the framework is the measurement issue that defines the geospace.

4.1 The current spatial mathematical basis can not meet the requirements

In accordance with the above four basic technical demands, the theory and methods for the spatial mathematical basis for GIS and digital earth are not satisfactory. For the super large-scale GIS space, the geospatial data framework should not continue to use the original spatial mathematical basis of maps. As we know there are lots of methods for
the latter. But which one is suitable? The map projection theory for map spatial mathematical basis can solve the transformation of the rotated ellipsoidal surface onto the plane, however, various deformations are produced during the transformation. Among them the angle distortion and length distortion are the most typical ones. And in some cases they are not convertible. The larger the area is, the bigger the distortions are. To moderate the deformations, the theory and methods of map projections take three measures:

1) To limit the area size and precision for controlling the two kinds of distortions. For example, in Gauss projection, for the maps at scales smaller than 1: 10,000, a meridional zone of six degrees is taken, while for those (larger than 1: 10,000) the zone is limited in three degrees.

2) The spatial distortion property is defined for certain applications. In this case the area distortion will be comparatively bigger. For economic maps equal-area projections are often applied. In this case the limitation for angular distortion is loose.

3) For maps of global viewing, projections without special limitation in angular and length distortions are considered. From the above-mentioned situations, we can see that for a plane or a small area like a plane, one kind of distortion may be zero and the other may be controlled in certain size. When the area becomes larger, one of the distortions will be difficult to be controlled; and when the area becomes very large, the other of the distortions becomes very large or even both are very large. This is the general rule of all map projections.

Therefore, taking the map projection as the framework for spatial mathematical basis can not meet the demands at all.

This practical situation produces some obstacles for the development of GIS. One of these obstacles is that there is not any precise measurement method and system up-to-date in the visualization situation. Of course it is already solved that the distance and azimuth between two points on the earth can be precisely calculated when their latitudes and longitudes are known. But it does not reach the condition that the visible is measurable. Another is that up to now all the analyses by GIS are made for small area and in Euclidean space. In this case planes are used to substitute the ellipsoidal surface, the static state substitutes for the dynamic one, and the precision is substituted by approximation. This is in contradiction with the flourish development of GIS.

4.2 The definition of spatial mathematical basis for geospatial data framework[2]

1) The referential ellipsoidal surface is directly used as the geometrical standard base for maps of the earth surface, and the geodetic system (B, L, H) is the referential system, where B, L, H are, respectively, the geodetic latitude, geodetic longitude and geodetic elevation of any geospatial point P, and

\[ H = H_{oh} + \xi \]

where \( \xi \) is the anomaly of elevation, and \( H_{oh} \) is the distance from \( P \) to geodetic level measured by levelling (\( h_{oh} = \) orthometric height).

2) Let the spatial point \( P \) be projected along the plumb line onto a selected two dimensional plane \( BOL \). \( BOL \) is a two dimensional measurement space, whose length and azimuth are defined with the length of the geodetic line and geodetic azimuth on the ellipsoid.

3) A transformation of viewing graph is taken as

\[ X = KL, \quad Y = KB \]

The two dimensional space \( BOL \) is expressed with planar \( X \) and \( Y \). Because it is a one to one topological transformation with nearly the same amount, so it can express the topological relation between spatial entities and their own geometrical characteristics with enough resolution, and the measurement can be easily realized by using the conditions on \( BOL \) under the special situation on computer.

4) Apply the latter two approaches above to various sections of data sources, and in combination with map projection calculation or numerical transformation, the traditional analog products can be worked out to connect the existing analog products
with digital ones smoothly.

- Let the $B, L, H$ in various data sources for different periods and systems be directly transformed into $B, L, H$ of the defined referential system;
- Let the data of plane graphs (topographical maps) and images of different periods and systems be transformed by using the broad sense numerical transformation method.

Therefore, the method that causes the separation and tight combination of two-dimensional graphs with the measurement system can totally satisfy the above four conditions, i.e., unification and continuity on the whole world, precise measurement, suitable for different resolutions or scales, fulfilment of area of different size and position and different special applications.

Obviously, the above definition can be the only foundation for global geospatial information positioning, and on this basis, four dimensional and five dimensional data and even data of higher dimension can be integrated.

Such a GIS can be suitable for a very large area and even the whole world. As time advances, its advantage and meaning for the development of the geo-information science will become clearer.

5 Basic contents to be contained in the framework

The framework itself keeps the properties of systematization, unification and generality. Therefore, its contents should be based on the principle of information integration, and have a good property of processing and development. They should include the so-called four dimensional products, namely, the digital raster graph (DRG), the digital elevation model (DEM), the digital orthophoto map (DOM) and the digital line graph (DLG). These four contents and their forms should be improved.

5.1 The spatial mathematical basis should be improved

In the US only the geographical network is defined for DEM, while the instruction committee of Global spatial data infrastructure and the working group recommended "to define a sole standard spatial referential body for geodetic coordinates to be used by various countries as standard ..."[4]. The authors think that serving the same aim, improvement should be made according to the modern development of science and technology. This means that the four dimensional products should not go along the "orthographic method", i.e., the spatial limitation of Gauss projection.

The Mercator projection in the conformer projection family keeps the property of loxodrome which is very convenient for navigation and has been applied to chartmaking since the 16th century. It was much earlier than the Gauss projection and the Universal Transverse Mercator Projection (UTM) used for topographical maps.

The development of conformer projection is tightly connected with technical means of the time. That is to say, when the map is only printed on paper, and cartometrical tools are traditional ones, such as the protractor, compasses, ruler and planimeter, etc. Today, the necessity and possibility have changed a lot. Of course, for the paper maps, the cartometrical tools did not change, so the Gauss or UTM projections are still widely for topographical maps, while the Mercator projection for sea charting. However, there exist the following problems:

1) In theory and practice, there is not any seamless orthophotographic set for most of China's provinces and for a nationwide system. Taking Guangdong province as an example, it spans three three-degree zones or two six-degree zones and contains 6,500 sheets of orthographic image map at scale 1:100,000. It can never be seamless.

2) The so-called "seamlessness" is not just for watching. Its basic meaning is that there are no unified coordinate system and spatial analysis. Pseudo-seamless technique can be used for watching on the screen. For example, when the screen map is wandering to the neighboring map on next zone, and the latter can be rotated with an angle of meridional convergence, the seam can be omitted temporarily. But at the corner of four map sheets, no rotation can mend the gap, and the defects for three dimensional and four dimensional data are much more than the above mentioned situation.

They will seemingly cover the discontinuity and sur-
face contradiction but cause the deep basic contradiction for spatial analyses.

3) For the data of other scales, for example, maps and images at scales smaller than 1:1,000,000 and DLG and DEM, there does not exist the orthographic image. What can we do then? Geographic informations of different resolution have their own applications. It is unreasonable and impossible to abandon them, and it does not conform with the reality of remote sensing technical practice.

4) The form of products should be coordinated with its ways of application. People can no longer use any terrestrial digital product. They would like to use computerized cartometric technique in quicker, more accurate and more convenient ways. In this case, the cartometric work in ellipsoidal space will be as easy as in Euclidian space. Then, what difference still exists between the terrestrial digital products of conformer or equal-area projections? Is it necessary to show favoritism to one of them?

Conformer projection had its flourishing days when the throwing weapons were developing. Today, the aim of application is greatly widened. The production form and the application form of terrestrial digital products have changed a lot. It is not necessary to “tailor a garment” for such new “maps”.

In the system of cartographic algebra, the whole global measurable cartometric operation can be realized with obtainable high precision in various resolutions and show the necessary loci in real time. In other words, if a correct geospatial mathematical basis is adopted, people can realize those work, which originally made on maps, with better, quicker and more accurate results.

As to the GIS and the terrestrial digital products should serve the analog products, to produce visualized hard paper copies for conventional use is necessary. Transforming the spatial mathematical basis into the necessary mathematical basis needed by hard copy products is already an easy and quick process without any difficulty.

Therefore, in GIS the conception of conformer, orthographic, Gauss or Mercator projections is not necessary, especially in the situation of large areas and on computer.

5.2 Improvement is convenient and can be realized

The essence of the above-mentioned improvement, from the aspect of two dimensional visualization graph, is to change the Gauss or UTM projections into equidistant secant (or tangent) cylindrical projection.

For vector data of DLG, the inverse transformation formulas of Gauss projection can be accurately and conveniently used.

For DRG and DOM, the original production technology may be maintained and the digital map projection transformation software for raster data can be used rigorously, easily and quickly. In this case, DOM becomes DIM (digital image map), because there is not great difference between them on large scale maps.

The DEM formed by square kilometer nets on Gauss projection is in different structure from DEM formed by geographical nets[4]. Therefore, it cannot be transformed by inverse calculation or interpolation, otherwise, it will be expensive and the effect will be low. The original contour line map can be transformed to obtain the new data of contour line and elevation points (in geodetic coordinates). On the basis of this result, the establishment of new DEM in geographical nets can be fulfilled by one interpolation.

Since the triangles of TIN net on spherical surface are rather small, theoretically, the linear interpolation used on plane can be used to construct DEM with the same method but different data. This is very convenient and accurate.

For newly established large scale GIS and geoinformation engineering, the application of spatial mathematical basis for “digital earth” should be considered.

According to the above principle, the maps and data at scales of 1:250,000, 1:1,000,000, 1:4,000,000, 1:40,000,000 can be totally transformed into systematic digital data, which means that we have data at any scales in the same spatial framework.
6 Establishment of spatial digital framework

The above-mentioned spatial data can be integrated into a geospatial data framework system, which will be an open and sustainable system with integration of vector and raster modes and easy to update and will become mathematically rigorous.

This is a real seamless framework with multi-resolutions, which can connect and supplement the original analog products, the map series. Furthermore, it is a geospatial framework with epochal characteristics linked with the digital earth.

Furthermore, it should have the following functions.

1) In the spatial database of a large region or even the whole world, it can be used for integration, checking, wandering, querying, precise measuring and analysis of the spatial data with different resolutions.

The precise spatial analysis is the main function of all GIS construction. Without a real seamless unified system, it is impossible to do dynamic spatial analysis for a large region. It is obvious that the analysis of the whole world and its resources, such as the greenhouse effect, ocean current, very large water conservancy project, desert moving and protection, the large environment and ecological engineering, mineral resources, etc.

The most important function of map, the analog geoinformation product, is to visualize cartometric operation, but the method is complex and its accuracy is low. Therefore, the terrestrial digital product should enhance and fundamentally solve the precise cartometric problem.

2) The graphic data formed by vector can be overlaid onto image data in translucent form to update the data and can be used for images of various resolutions.

3) Realize the image in the required resolution and the pyramid-like map self-adaptation and multi-resolutions from the scale of 1: 40 000 000 to 1:500.

4) Realize figure, image, and precise DEM of 2.5 dimension with the basic function of query, wandering and precise analysis.

5) All spatial data can be transferred to other GIS, if necessary.

6) According to demands, visualized products and maps can be produced in sheets or regions as the user asked.

7 Conclusion

This paper is fully agree with the suggestion made by Academician Li Deren and his colleagues. For the establishment of the spatial mathematical basis of the framework, a new idea has been put forward and the contents of the framework are also considered.

Just as many scholars agree that the spatial mathematical basis of the digital earth “should meet the developing direction and demands of the geoinformation technique”. The authors hold that it will be adopted and will produce wide social and economic benefit.

References

1. Li D R, Gong J Y, Zhu X Y, et al. (1998) Design and implementation of digital geospatial data framework in China. Journal of Wuhan Technical University of Surveying and Mapping, 23(4):297-303 (in Chinese)
2. Hu P (2000) The research report of the spatial mathematical basis for large scale GIS and terrestrial digital products. Research Report of 2000 Surveying and Mapping Science and Technology Funds (in Chinese)
3. Holland P (1999) The global spatial data infrastructure initiative and relationship to the vision of a digital earth. Towards Digital Earth — Proceedings of the International Symposium on Digital Earth. Beijing: Science Press.
4. Li G J, Hu P (2000) Data transformation and algebra isomorphism in GIS. Journal of Wuhan Technical University of Surveying and Mapping, 25(4):312-317 (in Chinese)
5. Hu P, Wu Y L, Yang C Y, et al. (2001) Research on system space mathematical base of large-scale GIS and the digital earth. Geomatics and Information Science of Wuhan University, 26(4):296-301 (in Chinese)
6. Chen J Y, Liu J W (2002) Towards the new creation of surveying and mapping in the 21 century. Newspaper of China Surveying and Mapping, Feb. 26 (in Chinese)