FOLDED MAP AND ATLAS DESIGN BASED ON THE GEOMETRIC PRINCIPLE

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Abstract

This paper presents two different types of packaging of geographical information guided by the geometric principle. One is an easy-to-fold/unfold map based on the result obtained from the space engineering research, and the other is a novel design of atlas solving the problem of discontinuity at the page borders.

Introduction

After the invention of paper in ancient China, the paper has been continuously the main media used for maps and atlases. Even if recent electronic media are becoming a boom, the trend will not be changed substantially in future. Therefore, designing of packaging forms for paper maps and atlases remains as one of major concerns for map publishers. The packaging of paper is affected by the intrinsic properties of paper. Among them, the nearly inextensional property is the major constraint posed on the packaging design. In mathematical words, it is said that the Gaussian curvature at any point of the surface of a paper should be zero as well as invariant for any transformation of the form. This is the principle that can be a constraint as well as a guideline for design. This paper presents two different types of packaging of geographical information guided by the principle. One is an easy-to-fold/unfold map based on the result obtained from the space engineering research, and the other is a novel design of atlas solving the problem of discontinuity at the page borders.

Part I Easy-to-fold/unfold map design

The packaging of a large expansion of thin planar material into a smaller volume is the major problem of large space structures in near future. The missions such as the solar power satellites, solar sails, and large antennas would not be possible without solving that packaging problem. In 1970, the present author presented a particular surface called “the developable double corrugation surface” (DDC surface) [Miura, 1970]. It is the abstract surface obtained from contracting an infinite plate bi-axially within the plane of the plate. It should be noted that the surface fulfills the geometric constraint mentioned above. This proposition was proved later by the numerical study [Tanizawa and Miura, 1978]. The particular properties of this corrugated surface prompted the author to apply it to packaging and deployment of large space structures [Miura, 1980]. At the same time, the application of this concept to map design was studied [Miura and Sakamaki, 1977]. The “Map of Venice”, based on the concept was thus published with the support of Olivetti Corp, Japan [Miura, 1978]. The result was reported at the ICA Conference in Tokyo [Miura, et al, 1980]. This type of map, even though it demonstrates favorable properties as a folded map, has not widely been used because of difficulty in machine folding. Recently, a method of mass production became possible to meet commercial needs. It seems adequate to report the summary of design principle and properties of the concept in this occasion.

Geometry of the developable double corrugation (DDC) surface

The developable double corrugation surface is generally characterized as the repetition of a fundamental region consists of four identical parallelograms as shown in Fig. 1.

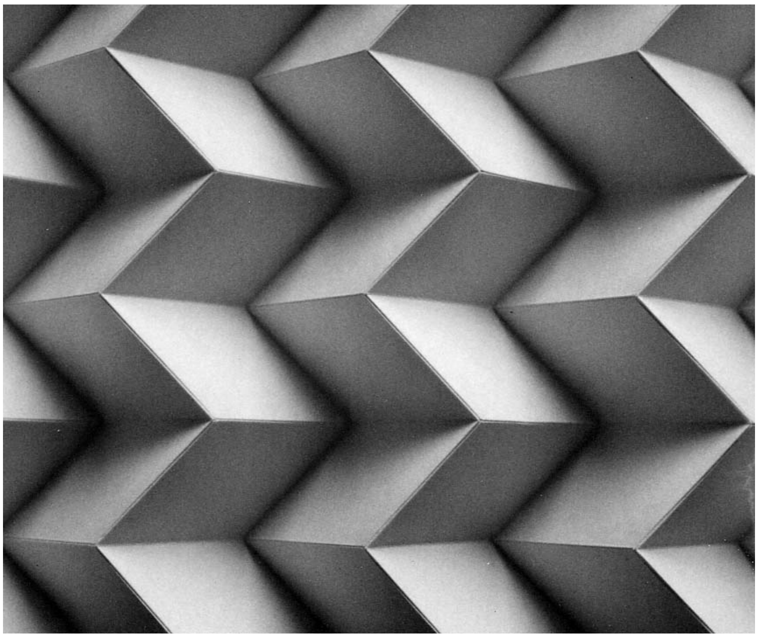

Fig. 1 The developable double corrugation (DDC) surface

The DDC surface is a generalized surface and it includes various shapes depending on its parameters. The only limited ranges of parameters of the DDC surface are adequate for folded map design. The most influential parameter is the zigzag angle□, which is the offset angle from the otherwise straight fold lines. In general, if the angle □ is large, the packaged volume is not small. On the contrary, if the angle□ is small, say 1 degree, the folding/unfolding process is not smooth. The appropriate range of the angle□ is from 2 to 6 degrees. After the disclosure of the concept of folded map design at ICA Tokyo, this type of folding is called “Miura-ori” among the world of map as well as origami (paper folding). In the following, the word Miura-ori is used in place of generalized DDC surface.

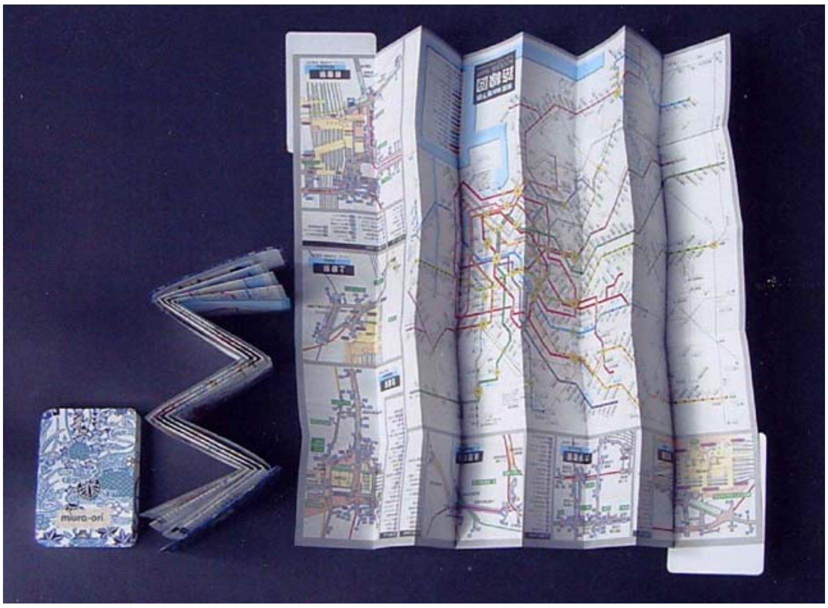

Fig. 2 Miura-ori map for Tokyo Transit (courtesy of ORUPA, Ltd.)

Behaviors of Miura-ori map

A typical design example for approximately A-2 size is shown in Fig. 2.

<Automatic folding/unfolding capability>

The Miura-ori map is easily unfolded by pulling the diagonal ends of it. Pushing the diagonal ends of it results in the folding. Both process are almost autonomous. This behavior is due to the fact that the map has the mechanism of a single degree of freedom. This is the reason why the concept has been used for the space solar array structures.

<Preservation of sign of folds>

In terms of origami science, the mountain fold and the valley fold are called, positive and negative fold, respectively. An arrangement of the folds signs, therefore, defines completely the shape of an origami work. The arrangement of folds signs for Miura-ori is unique, and the movement of every fold is linked together. Since it has the mechanism of a single degree of freedom, the sign of every fold is preserved. There is no possibility of missing the sign of any fold. On the contrary, for conventional, normally folded map, there is always two ways per a fold and the total number of ways of folds is very large. Folding back the map in a wrong way is the major cause of the fracture of paper at folds and nodes.

<Strength of folds>

Another fact relating to the strength of the present map is due to the offset of nodes. As it can be expected, when the map is completely folded, there are always offsets between nodes because of the offset angle □. This design feature greatly reduces the strains at the vicinity of nodes because of the offset. For conventional normally folded maps, the multiple of nodes are stacked eventually at a single point. It causes high strains at the vicinity of nodes. This is another weakness of the conventionally folded maps.

The preservation of the folds sign as well as the offset of nodes contributes greatly to the durability of the Miura-ori map. Because of this property, it does not need any means to strengthen paper, such as, plastic laminating.

Part II Atlas design for solving the discontinuity at the page borders

The north-south problem of atlases

The atlas discussed in this paper is the type of road atlases, which covers a continuous range of an area. Since, such an atlas covers essentially a two-dimensional space, the address for any orthogonally divided area should be expressed as the matrix form (m, n) as shown in Fig. 3. The west-to-east pages are arranged in “rows,” while the north-to-south pages are arranged in “columns.” The “window” indicated by a couple of rectangles in the figure is a spread of the atlas, where the needed matrix element should be brought in. The annoying property of conventional atlas design is the break of continuity of 2-dimensional information at the north and south borders of pages. One feels a difficulty in when one wants to go south or north crossing the border of the current page. In Fig. 3, if one goes from page (2, 4) to the geographically adjacent page (3, 4), one has to search page (3, 4) in the long array of pages. It is because conventional atlases are almost exclusively arranged in “rows” only. It consists of joining strips of row elements to make a long single strip, the one-dimensional form. Without an excellent ability of memory on figures, most likely one will lose the memory of the previous page. In this paper, this problem on the “southward or northward trip” along the columns is called the north-south problem.

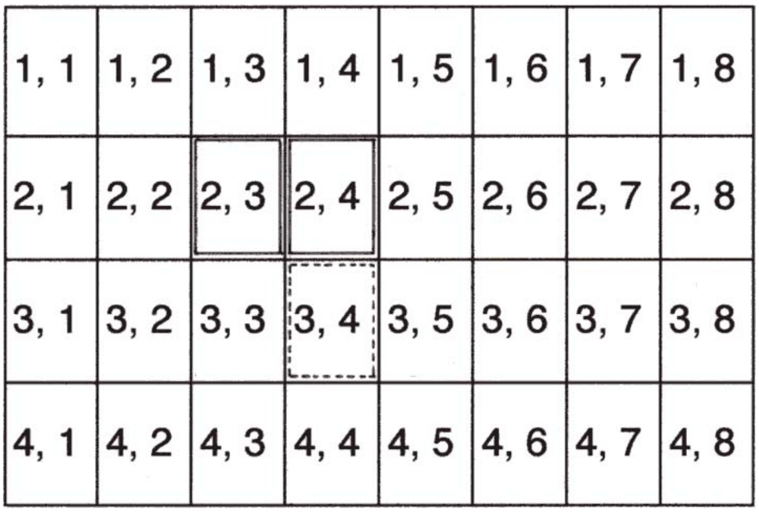

Fig. 3 The north-south problem of the atlas expressed in matrix form (m=4, n=8)

The solution of the north-south problem seems to be impossible to obtain because of its strict geometric constraints. With the help of geometric principles, the author found that the present atlas problem could be converted into the map-folding problem.

Conversion to the north-south problem of atlases

In Fig. 3, the rectangular lattice represents the abstract matrix expression of a covered area of an atlas, and thus it does not mean any physical object, that is, a map. However, if it is considered as a real map, the present problem can be transferred to the north-south problem of a map, provided it is to be only locally unfolded. After a process of trial and error, the author felt that it is impossible to solve it under the geometric constraint, that is, the Gaussian curvature at any part of the paper surface must be zero throughout the folding/unfolding process. It seemed that the only way to overcome this difficulty is to introduce cut lines to avoid the constraint without violating the invariancy of the Gaussian curvature.

Figure 4 shows fold and cut lines of a rectangular sheet of paper. The mountain lines, the valley lines, and the cut lines are indicated with solid, broken, and double broken lines, respectively. The resultant model following this design is shown in Fig. 5.

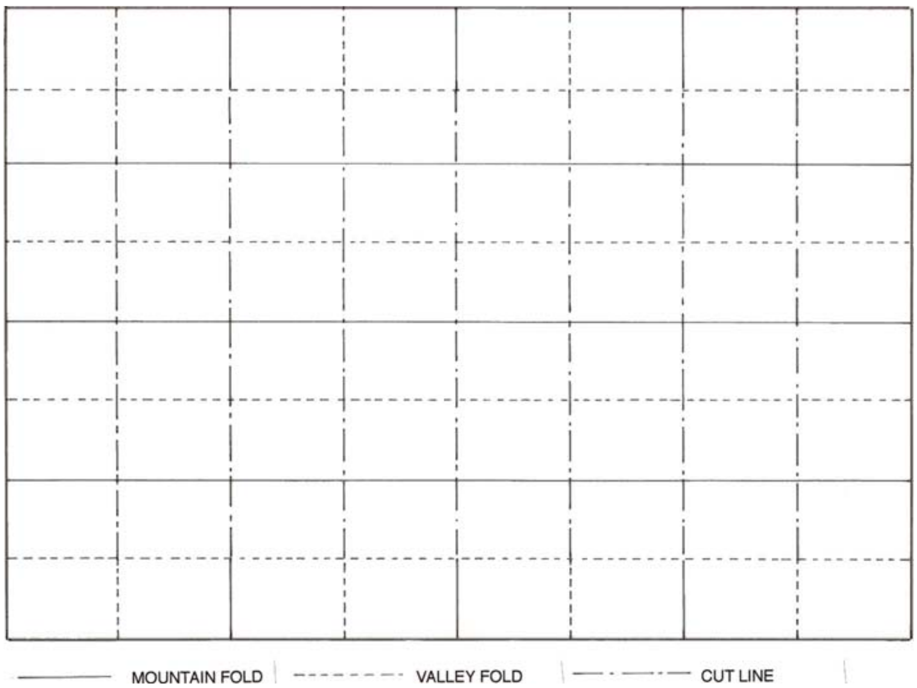

Fig. 4 An arrangement of fold/cut lines solving the north-south problem of map (m=4, n=8)

The principal features of the model are:

- it consists of several blocks
- a bundle of pages are fixed on both sides of each block
- each page is divided by the horizontal valley fold
- each page is double-woven
- each page is opened/closed vertically
- left and right pages are independent.

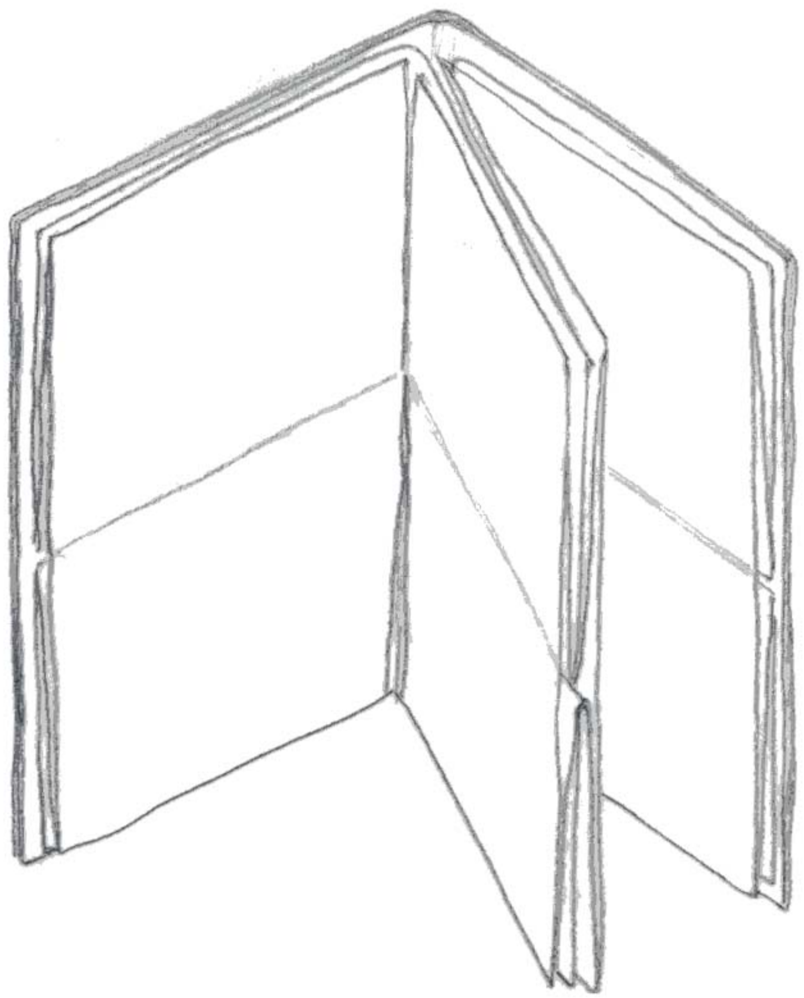

Fig. 5   Map model for solving the north-south problem (m=3, n=4)

With this construction, a sheet of rectangular paper turns to a mechanism, which is similar to the well-known game. The function of the map can easily be understood by means of a scheme as shown in Fig. 6.

In this scheme, a specified row and a column following the matrix algorithm identify each page. Relative to the fixed window, each page has a capability to scan in lateral (rows) as well as vertical (columns) directions. Let it be assumed that, at first the pages (2, 3) and (2, 4) are in the window as indicated in Fig. 6. A north-south trip from page (2, 4) to page (3, 4) on the map is simply to turn a page in the vertical direction. Thus, it is clear that the north-south problem of the map is solved in this way. This solution can be readily applied to, with some modifications, practical design of particular maps. However, the present purpose of this paper is to solve the north-south problem of the atlas and not the map.

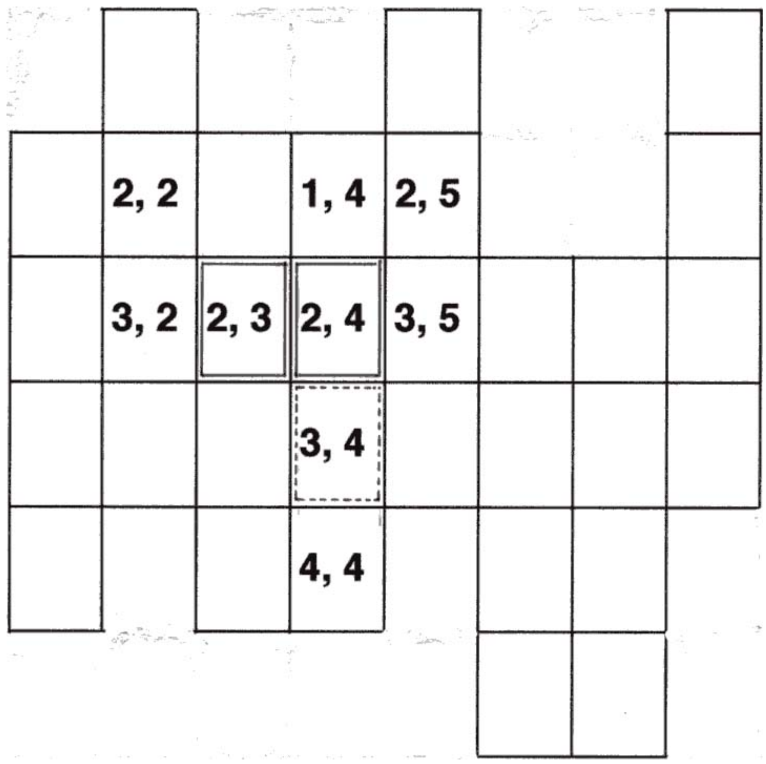

Fig. 6 Function of the map model for solving the north-south problem (m=4, n=8)

The atlas design solving the north-south problem

If we carefully inspect the block of vertical pages of the model, we know that each sheet is formed into double woven construction. The inside pages are dummy and useless. This construction is due to the process started from a continuous sheet of paper printed only one side. If we neglect the above process and look the model topologically, the double-woven pages can be replaced by a single sheet printed on both sides. The result is surprisingly simple. It consists of several booklets bound laterally, where each booklet is arranged vertically as shown in Fig. 7.

Some design principles are:

- relatively stiff base sheets for the blocks
- a ring type binding is recommended
- the function is similarly explained by Fig. 6
- some marks indicating the vertical (column) page number are necessary

It seems there is no difficult engineering problem in production of this type of atlas.

Thus the solution of the north-south problem of the atlas was completed.

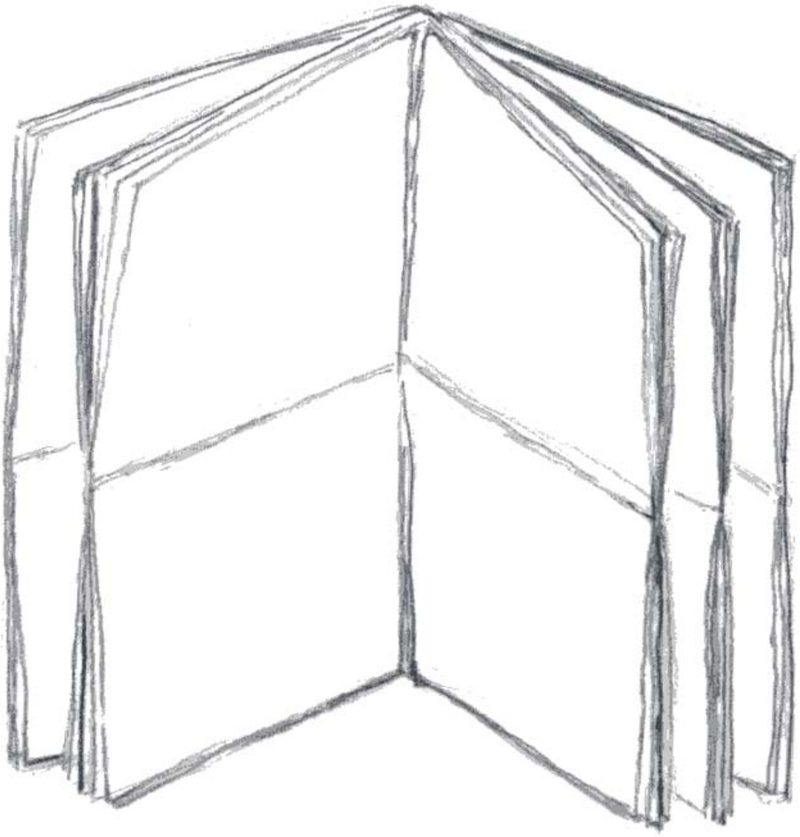

Fig. 7 The atlas design solving the north-south problem (m=5, n=8)

Conclusion

This paper presented two different types of packaging of geographical information. One is an easy-to-fold/unfold map and the other is an atlas solving the problem of discontinuity at the page borders.

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