THE NEW REFERENCE FRAME ABOUT THE SPATIAL ORIENTATION EXPRESSION FOR WAY-FINDING

Zhang Jing [a], David M. Mark [b], Zhang zheng-rong [c]

[a] Capital Normal Univ. 100037, Beijing , China Email:zhangjings@mail.cnu.edu.cn
[b] NCGIA, Buffalo, 14260, NY, USA dmark@geo.buffalol.edu
[c] Nanjing Univ. of Science and Technology, 210094, Nanjing, China

KEY WORDS: Orientation Relationship, Reference Frame, GIS

ABSTRACT:

Orientation relationship in the spatial relationship is an important in GIS. The orientation information about the urban environment is directly available to human beings through perception and is crucial for establishing their spatial location and for way-finding. People perceive the arrangement (layout) of entities in space, categorize them as spatial relationships, and describe them as spatial expression in language. This paper will propose the new type of the reference frame and its orientation system, and demonstrate the composition factors and the characteristic of the reference frames. We will illustrate its mathematics base and its formalization expression in mathematics. Then we will analyze some characteristics to make way-finding in such reference frame. In the conclusion, we suggest the further research about the orientation relation of the new reference frame.

1. INTRODUCTION

After what appears to have been a decline in the late 1970's and most of the 1980's in research concerning human understanding of space, there has been a renewed interest in this topic.[Scott M. Freundschuh, 1992]. The qualitative approach to the representation of spatial knowledge has gained considerable popularity in recent years. Humans reason in various ways and in various situations about space and spatial properties. The most common examples are navigational tasks in which the problem is to find a route between a given starting point and an end point. [Andrew U. Frank, 1992]. Spatial orientation information, specifically the direction information about the environment is crucial for establishing their spatial location and for way-finding. When talking about spatial representations, we have to talk about reference frames. A discussion on the different notions of reference frames can be found in Roberta [1998] and Levinson [1996]. As we have seen, there are numbers of different approaches and reference systems for representing spatial knowledge, for example, the projection-based model, cone-based model and double cross model and so on. Andrew Frank [1991] introduced two methods to partition the orientation, which are called the projection-based model, cone-based model and directions with neutral zone (See Fig. 1, Fig. 2). Freksa [1992] introduced the "double cross model" which is based on the projection-based model by adding the "view'. The expression of the orientation in different reference frame is different.

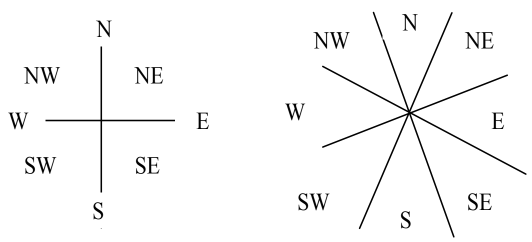

Fig.1 The projection-based model (left) and the cone-based model (right)

We will restrict our attention here to two-dimensional space, which is commonly used as a projection of the three-dimensional space. Thus, we can consider a scene to be made up of geometric objects (points, lines, and areas) variously arranged in the plane and possibly overlapping. [Daniel Hernandez, 1997]

This article addresses a new kind of reference frame. This approach is motivated by Beijing urban environment and is based on relative orientation information about the ring road and its sectors in each ring road. We will propose the new type of the reference frame and its orientation system, and demonstrate the composition factors and the characteristic of the reference frames. Its mathematics base and its formalization expression in mathematics will be illustrated. Then we will analyze some characteristics to make way-finding in such reference frame.

The remainder of the paper is organized as follows. In the second section, the new type of the reference frame is introduced: including the composition of the reference frame- the cross plus a series of run-in squares; the orientation of the reference frame- 12 kinds of the orientation; and its characteristics; while its mathematics base and its formalization expression in mathematics are illustrated in the third section. In the fourth section, its application and its characteristic to make way-finding in such a reference frame will be described and discussed, including the orientation being decided approximately; and the orientation being described accurately; and to formalize about the orientation easily. In the fifth section, we will present conclusions and suggest the directions for future work.

2. THE DEFINITION OF THE NEW REFERENCE FRAME

Geographic maps can be utilized to reason about cardinal directions between objects in the world. People use the cardinal directions in maps in a qualitative manner.
In local spaces, considering orientation relations generated by a reference frame raises the problem of choosing a specific reference frame together with a label.

A new frame of reference must be specified with three characteristics:

the origin of the coordinate system (independent if one assumes the conventional orthogonal coordinate system or not);the orientation of the coordinate system, given by the direction of its primary axis (even if the secondary axis is not orthogonal to it);the handedness of the coordinate system (i.e. the relations of the axes). [Andrew U. Frank: 1997]

In this paper, we define a new kind of reference frame which includes the cardinal direction same the cone-based model and a series of the squares as ring.

2.1 The diagonal of the squares plus a series of the squares

The reference frame is the combination of the cone-based model and a series of the squares. This is a new model about the reference frame.

Reference systems are essential in contexts in which the same spatial constellation can be described from different 'perspectives'. Therefore, different descriptions are used for the same spatial constellation of objects in maps. Which reference systems are used in maps or a map interpreting context and which features constitute these reference systems?

Absolute reference systems have a fixed direction which is-in the case of maps-provided by the North Pole. This direction is specified for every point on a map. The orientation of a map in the world is irrelevant. The description of spatial constellations is independent of a point of view and the relation between the reference object and the localized object is binary because only the position of the two objects are required [Levinson 1996].

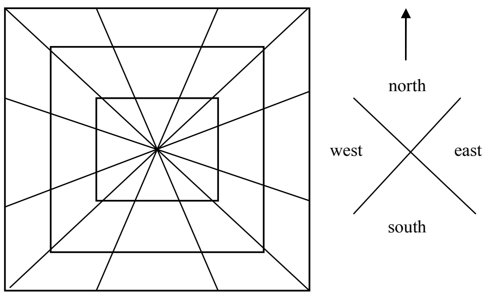

Fig. 2 The concept of reference frame

As mentioned above, we adopt the cone-based model as the direction reference. The coordinate axis including two diagonal axes partitions the 2D space into four sub-spaces, which express the north, east, south and west in clockwise orientation respectively in the cone-based method; while the direction of the cross represents the northeast, northwest, southwest and southeast respectively.

2.2 The orientation (twelve directions)

A new way of projecting the symbolic objects was demonstrated, that contrary to the technique used, so far, is not perpendicular to the coordinate axes. It was demonstrated that the projections could be made in 12 directions.

The non-perpendicular approach can be used for determination of directions as well [Erland Jungert, 1992]. This is particularly useful in reasoning about geographical directions like north, west and north-east, etc. In such a directional system, we often use east/west/south/north*3 different orientation (east, west, middle or north, south, middle) (each road is divided into 3 segments.). Therefore, there are 12 orientation of in such new reference frame. The 12 directions are of particular interest, that is {NW, N-middle, NE, EN, E-middle, ES, SE, S-middle, SW, WS, W-middle, WN}. To illustrate this, only the 3 parts in each direction of the each quadrant are considered. However, it is a simple task to generalize the technique into the full space. The angle between the two dividing lines is 90°/3.

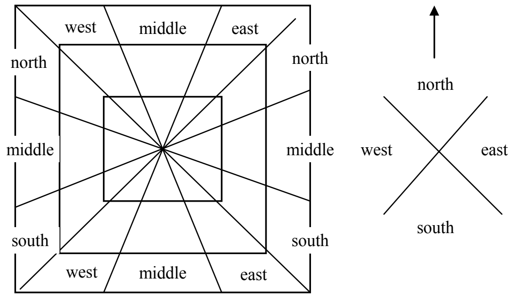

Fig. 3 The detail about the reference frame

We will analyze the sub-area by the main lines in Beijing following. The each ring road is divided four different segments which is name by the orientation. For example, the 4th ring road is divided by east 4th ring road, west 4th ring road, north 4th ring road and south 4th ring road. At each segment of 4th ring road, there are 3 parts.

2.3 The distance (three kinds of distance)

Cognitive considerations suggest the need for systems of distance relations organized along various levels of granularity, for example: a level with three distinctions close, medium, and far, a level with four distinctions very close, close, far, and very far, a level with five distinctions very close, close, commensurate, far, and very far, and so on [Daniel Hernandez, 1997].

The qualitative approach deals implicitly with uncertainty in that the next coarser level of distinctions is chosen whenever no decision can be made about the appropriate relation at a finer level. Most of the time, this is better than coming up with fuzzy membership numbers, which can be quite arbitrary. However, the general framework presented here is independent of the kind of boundary (sharp, fuzzy, overlapping) between the regions [Daniel Hernandez, 1997].

We propose a qualitative framework where some elements are needed to establish a distance relation: the center O, point M, cardinal distance d (totally four lines), primary distance c (totally eight lines), the other distance (the distance between any point M and the center O). The distance between the reference object M and the center O is expressed by dOM=d(O, M) (See fig. 4).

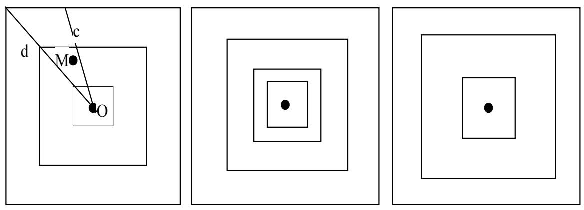

Fig 4 Different kinds of distance distinctions

There are three kinds of distances. The first kind is the equal-distance, meaning that the distance between two rings is equal. The second kind is the incremental-distance, meaning that the distance between two rings from centre outwards is incremental. The third kind is the descending-distance, meaning that the distance between two rings from centre outwards is descending. In this paper, we just propose these kinds of distance. However we don't analyze its characteristic and its mathematic base.

3. THE ORIENTATION FORMALIZATION EXPRESSION IN MATHEMATICS

3.1Polar coordinates expression in mathematics

Because the reference frame is composed of 12 directions, we can consider that the orientation coordinate at any point is expressed by polar coordinate and one 2-dimension array.

The way to express concretely is following:
The coordinate centre is selected to be the polar coordinate centre; the direction pointing to the true northwest is the direction of the polar axis; the coordinate at any point is denoted by one 2-dimension array(r, b), wherein r represents the distance of the point to the centre, b represents the angle departure to the polar axis.

By such polar coordinate, we can locate the point quickly: the direction can be decided by b; the distance can be decided by r. Also we can compute the distance between two points by this kind of coordinate: if M(r1,b1), N(r2,b2), then $MN^2=r_{12}+r_{22}-2*r_1*r_2*\cos(b_1-b_2)$

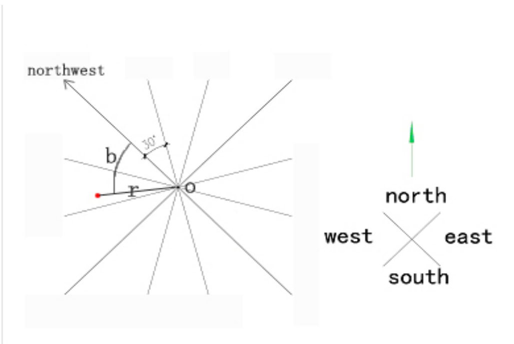

Fig. 5 The sketch map of the polar coordinate

3.2 The matrix expression in mathematics

We may consider that the orientation coordinate at any point can expressed by 4-dimension matrix because there are 12 directions in this coordinate.

The way to express concretely is following:
$A=[aij] \in R^{4\times4}$

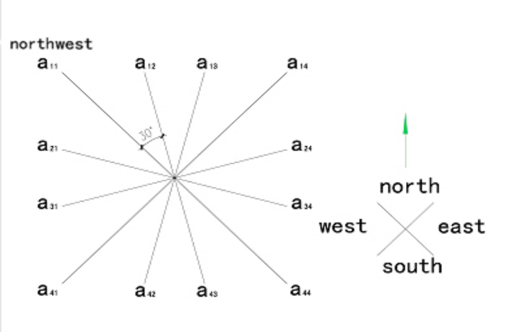

Fig. 6 The sketch map about the matrix expression

In the fig.6 , a_{11} represents the axis point to the true northwest, a_{12},a_{13},a_{14},a_{24},a_{34},a_{44},a_{43},a_{42},a_{41},a_{31},a_{21} accordingly represent the next axis (according the clockwise), a_{22} represents the distance to the center of the coordinate. If a_{23}=0, then the point is not on one of 12 axes; if a_{23}=1, then the point is on one of 12 axes. Meanwhile a_{32}=0, a_{33} =0 respectively.

a_{11}	a_{12}	a_{13}	a_{14}	a_{11}	a_{12}	a_{13}	a_{14}	a_{11}	a_{12}	a_{13}	a_{14}
a_{21}	a_{22}	a_{23}	a_{24}	a_{12}	a_{22}	0	a_{24}	a_{21}	a_{22}	1	a_{24}
a_{31}	a_{32}	a_{33}	a_{34}	a_{13}	0	0	a_{34}	a_{31}	0	0	a_{34}
a_{41}	a_{42}	a_{43}	a_{44}	a_{41}	a_{42}	a_{43}	a_{44}	a_{41}	a_{42}	a_{43}	a_{44}

Fig.7 The matrix model expression

(The matrix model (left), point is outside of the axis(middle), point is on the axis (right))

Situation (1):
If the point is not on one of 12 axes, then a_{23}=0, a_{22} is evaluated the distance to the center, the two factors corresponding two axes besides the point are evaluated the distance of this point to the axes, other factors is evaluated zero.

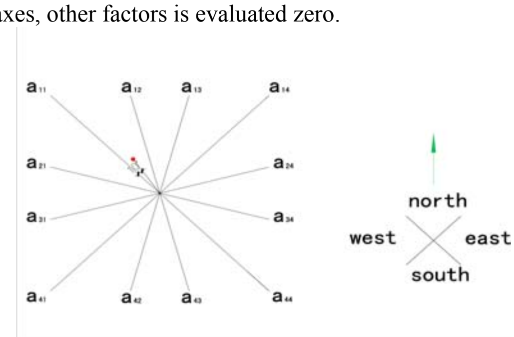

Fig 8 The sketch map in the situation (1)

For example, the coordinate of point N (the red point) is following:

1/ 2cos20°	1	0	0
0	1/ sin20°	0	0
0	0	0	0
0	0	0	0

Situation (2):
If the point is on one of 12 axes, then a_{23}=1, the corresponding factor to this axis and a_{22} is evaluated the distance to the center, other factors is evaluated zero.

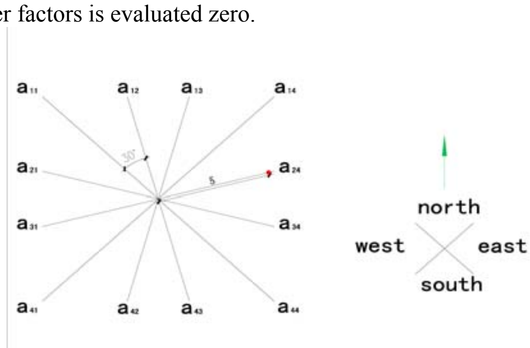

Fig. 9 The sketch map in the situation (2)

For example, the coordinate of point M (the red point):

0	0	0	0
0	5	1	5
0	0	0	0
0	0	0	0

Complementary explaining:
In such two different situations, the value of a_{22} can be deduced by other factors which value is not zero.

We can decide the orientation quickly by this matrix method to express the coordinate of the point:
The first step: to estimate the value of a_{23}, 1 or 0.
The second step: if a_{23}=1, then to search the non-zero factor, finally to decide the orientation by the location in the matrix.
The third step: if a_{23}=0, then to search the non-zero factor, finally to decide the orientation by the location in the matrix.

4. THE CHARACTERISTIC OF ITS APPLICATIONS

The most basic reasoning task is to exploit the spatial knowledge and spatial information encoded inside a representational framework. Two cases can be distinguished according to the completeness or incompleteness of this knowledge and information. [Laure Vieu, 1997]. When information or knowledge is incomplete or uncertain, one can try to infer possible facts on the basis of hypotheses on the structure of spaces. When orientation is taken into account, it must be noted that it is purely static orientation. People can use local reference frame to deduce the direction. For example, Hernández [1994], Freksa [1992b], and Ligozat [1993] all express the contextual orientation of a located point with respect to a reference point, as seen from a perspective point. They apply to the reference point a local reference frame in which the frontal direction is fixed by the direction <perspective point, reference point>. These authors all take the relation algebra approach and describe the inferential behavior of the primitive relations in transitivity tables.

In this part of the paper, we will describe and discuss its characteristic to make way-finding in such a reference frame. We compare the power and characteristics between 4 cone-based and 12 cardinal directions in the spatial environment, for example Beijing city as the case study.

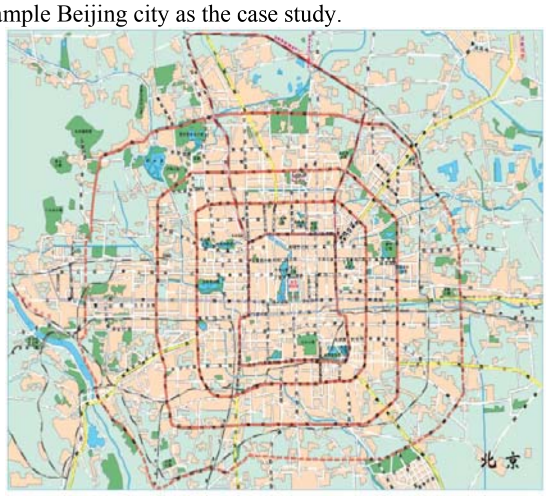

Fig. 10 Beijing city map

4.1 The orientation being described accurately and in detail

The power and characteristic about the frame of reference will be different in different spatial environment. The cone-based model can describe the 4 directions accurately. However the 12 directions model also can describe the 4 cardinal directions because it is based the 4 directions. For example, if there is a point on the model (See fig. 11), the cone-base model just can show that the direction of the point is north. However, the 12 directions model not only can show that the point is on the north, and the detail of the north can be showed, it is on the west of the north.

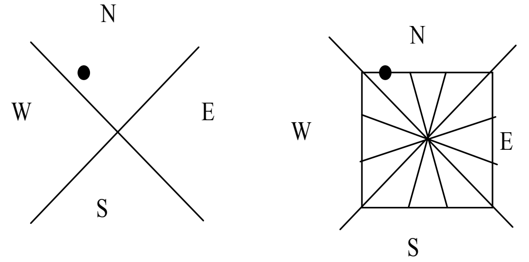

Fig. 11The comparison between the cone-based(left) model and the 12 directions model(right)

In such a reference frame, each quadrangular side is divided into 3 parts. We divide the area into 12 parts and each angle between the main adjacent axes is 30^o. First we can describe the direction about the location of the point-east, south, west, north, approximately. Later, according to the direction decided already, we can divide it into 3 parts, for example, north: north-east, middle, north-west. Therefore, the orientation being described is more detailed.

4.2 Both of the orientation and distance together to make way-finding

The direction in cone-based model can be described accurately, but the distance in such model can not be described now. We can express both direction and distance in the frame of reference proposed above. Therefore we can use both of the orientation and relative distance together to make way-finding.
In such a reference frame, there are a series of the squares which divide the area into different parts. For example, there are 6 ring roads in Beijing city, and there are 6 relative distances in each direction of 4 different directions. So we decide the location of the point according to the number of the ring road and direction. The whole area is divided into 6*12 parts. So if we search some point, we use just 1/72 parts of the area to decide the location of the point (See Fig.12).

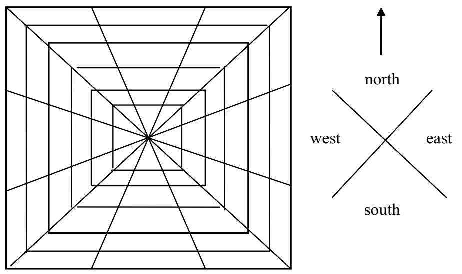

Fig. 12 the direction and its distance expression with ring roads

5. CONCLUSION AND FUTURE WORK

This paper presented a new type model about the reference frame for describing the directions. This is a typical example of qualitative reasoning, dealing with the orientation and distance. First we demonstrate the composition factors and the characteristic of the reference frames; then we illustrate its formalization expression in mathematics, polar coordinates expression using Euclidean distance and polar coordinate expression using Manhattan distance in the polar coordinate; finally we analyze and discuss its characteristic to make way-finding in such a reference frame. In the conclusion, we suggest the further research about the orientation relation of the new reference frame.

Although we have studied the main its composition factors and its characteristic in this paper, there are many work need to do further.

We will do some experiments of the cognitive psychology in order to illustrate further the characteristic by using this kind of new reference frame.

REFERENCES

Scott M. Freundschuh 1992 Is there a relation between spatial cognition and environment patterns? In A.U. Frank, I. Campari, U. Formentini (eds.) Theories and Methods of Spatio-Temporal Reasoning in Geographic Space, LNCS 639, Springer-Verlag Berlin pp.288-303

M.J. Egenhofer.1991 Reasoning about Binary Topological Relationships. In Proceedings of SSD-91, pp. 143~160

Frank, A.U. 1992 Qualitative Spatial Reasoning about Distances and Directions in Geographic Space. Journal of Visual Languages and Computing Vol.3,pp.343-371.

Z. Cui, A.G. Cohn, D.A. 1993 Randell. Qualitative and Topological Relationships in Spatial Databases. In Proceedings of SSD-93, pp.296~315

J. Renz, B. Nebel. 1999 On the Complexity of Qualitative Spatial Reasoning: A Maximal Tractable Fragment of the Region Connection Calculus. Articial Intelligence, 1-2:95~149.

D. Papadias, Y. Theodoridis, T. Sellis, and M.J. Egenhofer. 1995 Topological Relations in the World of Minimum Bounding Rectangles: A Study with R-trees. In Proceedings of ACM SIGMOD-95, pp. 92~103

Roberta L. Klatzke1998 Allocentric and egocentric spatial representations: Definitions, distinctions and interconnections. In C. Freksa, C. Habel, and K. Wender, editors, spatial cognition. An interdisciplinary approach to representing and processing spatial knowledge, volume 1404 of Lecture Notes in Artificial Intelligence, Springer

B. Bennett.1997Logical Representations for Automated Reasoning About Spatial Relations. PhD thesis, School of Computer Studies, University of Leeds

R. Goyal and M.J. Egenhofer. 1997 The Direction-Relation Matrix: A Representation for Directions Relations Between Extended Spatial Objects. In the annual assembly and the summer retreat of University Consortium for Geographic InformationSystems Science, June.

G. Ligozat. 1998 Reasoning About Cardinal Directions. Journal of Visual Languages and Computing, 9:23~44

R. Goyal and M.J. 2000 Egenhofer. Cardinal Directions Between Extended Spatial Objects. IEEE Transactions on Data and Knowledge Engineering, (in press), http://www.spatial.maine.edu/~max/RJ36.html.

K. Zimmermann 1993 Enhancing Qualitative Spatial Reasoning- Combining Orientation and Distance. In Proceedings of COSIT-93, volume 716 of LNCS, pp. 69~76

E. Clementini, P. Felice, Hernandez D1997 Qualititative representation of positional information, Artificial intelligence, pp.317-356

S.C. Levinson1996 Frames of reference and Molyneux's question. In P. Bloom, M. A. Peterson, and N. Nadel, editors, Language and space. MIT Press, Cambridge, MA

Frank, A.U1991 Qualitative spatial reasoning with cardinal directions. Proc. Seventh Austrian Conference on Artificial Intelligence, Wien, pp.157-167, Springer, Berlin

Christian Freksa1992 Using Orientation Information for Qualitative Spatial Reasoning. In A.U. Frank, I. Campari, U. Formentini (eds.) Theories and Methods of Spatio-Temporal Reasoning in Geographic Space, LNCS 639, Springer-Verlag Berlin

Vieu, L. 1997 Spatial Representation and Reasoning in Artificial Intelligence. In: O. Stock (ed.) Spatial and Temporal Reasoning. Dordrecht: Kluwer, pp. 5-41.

Zimmermann, K1995 Measuring without measures. The Δ-Calculus in A. U. Frank & W. Kuhu (Eds.), Spatial inforamiton Theory: A theoretical basis for GIS (Proceedings COSIT'95) (pp. 59-67). Berlin etc. : Springer

Mark, D. M., M. D. Gould, and M. McGranaghan 1987 Computerized navigation assistance for drivers. The Professional Geographer, 39, 215-220.

McDermott and Davis1984 D.V. McDermott and E. Davis. Planning routes through uncertain territory. Artificial Intelligence, 22:107-156

Dutta1990 Qualitative Spatial Reasoning: A Semi-Quantitative Approach Using Fuzzy Logic. In: Design and Implementation of Large Spatial Databases (Eds. Buchmann A, Günther O, Smith T R and Wang Y-F) Springer-Verlag, New York, pp.345-364

Zadeh L.A. 1974 On the analysis of large scale systems. — Systems Approaches and Environment Problems (H. Gottinger,Ed.), Gottingen: Vandenhoeck and Ruprecht, pp. 23–37.

Erland Jungert,1992 The Observer's Point of View: An Extension of Symbolic Projections.pp.179-195

Daniel Hernandez1997 Daniel Hernández: Qualitative vs. Fuzzy Represenations of Spatial Distance. pp.389-398

Andrew U. Frank1998 Formal Models for Cognition - Taxonomy of Spatial Location Description and Frames of Reference. Pp.293-312

A. Tarski1946 Introduction to Logic and to the Methodology of Deductive Sciences. Oxford University Press, New York, second, revised edition, Freksa, C. 1992. Using Orientation Information for Qualitative Spatial Reasoning . In Frank, A. U., Campari, I.,and Formentini, U., editors, Theories and Methods of Spatial-Temporal Reasoning in Geographic Space, pp. 162.178. Springer, Berlin.

Acknowledgements

Acknowledgements of support for the paper are welcome. This project is supported by the Beijing Natural Science Foundation, and the number is 4042011