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Map spatial cognition research and spatial information visualization

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Map spatial cognition research and spatial information visualization CHEN Yufen (Inst. of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China) Abstract: Along with the advances in computer sciences in recent years, visualization has been developed to embrace new functions. The electronic map in a spatial information visualization system is an electronic tool of human spatial cognition and has more advantages in supporting human spatial cognition than a printed map. Investigations on the ability of human spatial cognition are increasingly drawing attention of cartographers. In this background, map spatial cognition research is attached importance to cartographers again. Cognition-based visualization systems are intelligent systems that serve human spatial cognition efficiently. Developing adaptive multi-perspective visualization systems of spatial information as one kind of these systems is a main goal of our research. This paper discusses the necessity and the characteristics of map spatial cognition research. The cognitive issues involved in spatial information visualization and major contents of cognitive research in the design of adaptive visualization system are presented. Finally, the experimental methods of electronic map visual cognition are introduced. Key words: spatial information visualization; electronic map; map spatial cognition; visual cognition; cognitive science; visual cognitive experiment CLC number: P283.7 1 Introduction The applications of the technology of computer graphics, multimedia, Internet and Virtual Reality in cartography have exerted tremendous impact on the traditional cartographic theories and technologies. Owing to the introduction of the concept and the technology of Visualization in Scientific Computing (ViSC), the functions of maps are transferred from static and two-dimensional representation to dynamic, multi-dimensional and interactive exploration of spatial information. Moreover, the relationship between users and maps has been changed, which correspondingly requires the change of the way we view maps. The application of visualization technology in cartography enhances the role of maps in society, especially as a spatial cognition tool. In cartographic visualization environment, the user interface is in most cases an electronic map, and the relationship between human and computer is also that between humans and maps. For this reason, spatial cognition issues in the design of user interface have become map spatial cognition issues. The rules and principles of map spatial cognition, the cognitive models of map designers as well as map users and the methods of establishing and processing models, all these are the main contents of map spatial cognition researches. A spatial information visualization system guided by map spatial cognition theory will be an adaptive intelligent visualization system that can satisfy system users at different cognitive levels. 2 Map spatial cognition research Spatial cognition as a spatial information handling process is an important research area of cognitive sciences. It has been intensively studied b

y psychology, cartography, geography, computer sciences and Artificial Intelligence (AI). Map spatial cognition means the process of spatial cognition by using a map. 2.1 The roles of map in human spatial cognition Humans have never ceased the exploration of spatial geographical environment in which they live. The ability of processing spatial information, i.e. spatial cognition, is one of the basic abilities on which humans rely for survival. A map is a result of human spatial environment cognition and at the same time also a tool that supports human spatial cognition because it brings the communicating person and his geographical environment together. With the popularization of digital mapping and Internet, paper maps as a spatial cognition tool are being partially replaced by electronic maps. The electronic map in spatial information visualization system is an electronic tool that has revealed additional advantages in assisting human spatial cognition. Owing to the introduction of multimedia and Virtual Reality technology, maps have rapidly evolved from static to dynamic, from 2D to 3D. Social demands on and interests in electronic maps are increasing. Consequently, modern maps are expected to play more important roles than ever before. 2.2 The characteristics of map spatial cognition The characteristics of map spatial cognition are given in the following: · It covers a wide range. Map spatial cognition depends on the environment humans live in. As the consequence of the dramatic technical developments, the scope of environment is expanding from earth to universe and from real space to virtual space as far as a map can present it. · It concerns an unusual object. It is the map that the user gets along with. The map is not reality itself, rather an abstract description of the reality. A map represents spatial environment with its special cartographic language and the one using the map for his spatial cognition must understand this language at first. · It is dominated by visual cognition. While spatial cognition has to do with multiple modalities, map spatial cognition primarily involves the visual modality. · It demands high-level mental effort. As map spatial cognition is carried out by using a map and three-dimensional or more dimensional geographical environment information appears as abstract symbols on maps, it is not so straightforward to construct a mental image from a map as from the real environment. 2.3 The process of map spatial cognition 2.3.1 Input of spatial information In the process of map spatial cognition illustrated in Figure 1, the input of spatial information means to input stimuli (spatial information on map) from outside to human ' s sense organs. If the stimuli are originate from a paper map, only the visual organ will be triggered. If it is a multimedia electronic map or a Virtual Terrain Environment, multiple senses such as visual, hearing and touching will react in a cooperative way. 2.3.2 Processing of spatial information The processing of spatial information is mainly achieved by memory system and control system, that is, the processing of information in several phases including sensory register, pattern recognition, repeat, short-term memory, long-term memory and attention. The process of spatial information handling is also a process of cognitive mapping and its outcome is a mental map. 2.3.3 Process of controlling The processing of spatial information begins from sensory register that holds information for about one to several seconds, long enough for it to be initially noticed. Attention makes it possible for the observer to " mentally focus " on what he is interested in and ignore the surrounding stimuli. Pattern recognition converts the contents of sensory register into something more meaningful through a matching process with previously acquired knowledge stored in long-term memory. Visual information that has been registered and noticed may be sent into the short-term memory. Repeating makes the information stored in short-term memory be held a longer time and transformed into the information in long-term memory. 2.3.4 Output of spatial information The spatial information gained from map spatial cognition may be either stored in human mind in form of a mental map or exported in visual form of decision-making and interactive map. Figure 1 The process of map spatial cognition 2.4 The spatial cognitive model of interactive map information communication The process of mapmaking, which is a process of visualizing, can be regarded as a kind of spatial cognition behavior. The mapmaker changes previous knowledge structure in his mind and forms a new understanding of the region to be mapped, that is a mental map, through various means such as field work, reading maps, listening report, reading written materials and experiencing VR (Figure 2). On the basis of this cognitive mapping process, the mapmaker then brings his mental map into view in terms of symbolization (the means of map visualization). If it should be a dynamic interactive map, the mapmaker has to design a user interface as well. Figure 2 The spatial cognition model of interactive map information communication Map use is another spatial cognition behavior. Through map reading and pattern recognition, the user tends to modify his old knowledge structure, obtain new spatial knowledge and form his mental map about the mapped region. This is again a process of spatial cognition. By using a dynamic interactive map, the user can extract new spatial data from a database and analyze the map contents and represent the result of analysis or mental map formed in his mind. This real-time interaction is also a process of map visualization. 3 Cognitive issues in spatial information visualization 3.1 The necessity of researches on cognitive issues in visualization Cognitive issues are important to visualization because the utility of any spatial information visualization system depends to a large extent on how humans cognitively process the knowledge about spatial information. Research

on cognitive issues will help in the design of more useful spatial information visualization system. Cognitive issues involve questions about how humans acquire, store, manipulate, reason and communicate knowledge. Many important visualization research questions deal with issues of human cognition such as how experts and laymen conceptualize and reason about geographical space, how natural language expresses spatial information, how user interfaces should be designed to promote its efficiency, what the differences for the perception and interpretation of geographic information are among user classes with different knowledge background, gender, age and experience etc. Researches on cognitive issues in visualization help to provide a theoretical basis for building intelligent spatial information visualization systems. Due to lack of theoretical guide, a lot of current electronic maps and visualization systems have run into a rather chaotic state. There are too many functions and overloading contents in the user interface. Freewheeling designed user interfaces and toolboxes puzzle users greatly. Therefore, the design of spatial information visualization system urgently needs the guidance of the theory to assure its quality. That is to say, cognitive issues in spatial information visualization need a thorough study. 3.2 Some cognitive research topics in spatial information visualization An adaptive multi-perspective visualization system of spatial information is a cognition-based spatial information visualization system, guided by spatial cognition theory, user-centered, with the functions of self-organizing, self-adjusting and self-navigating. Its basic goal is, by studying the role of maps in human spatial cognition, to summarize the rules of human spatial cognition, integrate the theory and the principles of interface design in visualization system and provide relevant services to users according to their requirements, knowledge levels, tastes and information needs. The design of adaptive multi-perspective visualization system of spatial information must therefore take into consideration a number of broad categories of cognitive issues, including the following: · Cognition issues on 3D spatial information visualization. As means of spatial information visualization 3D terrain representation and Virtual Reality technology may enhance human's perception of real world in maps. Some research questions are: What advantages does 3D visualization have compared with 2D visualization? How can these advantages be utilized for the design of spatial information visualization system in order to avoid the overloading contents? · Cognition issues on multimedia applications in user interface. In most cases, system user interface is visual. But we need to know what effects the sound will have if it is added to user interface, how we can make use of the sound for user interface design, whether the sound will help or confuse the map user. From the cognitive point of view, it is more effective if sound variables are used in the user interface because it made full use of human's multiple modalities, but it remains to be confirmed by cognitive experiments. · Human cognition in dynamic visualization. Dynamic visualization could attract user's attention, and reflect some moving phenomena in real world. Blinking objects can make the user attentive in a very complex representation. Animation can be used to illustrate changes to a specific object or the whole scenery over time. Here again, the impacts of dynamic visualization need to be confirmed by cognitive experiments. · Intelligent visualization user interface design. The notion of intelligent visualization user interface means, on the one hand, the design of user interface depending on system user's demand, their knowledge level and spatial cognition ability, and on the other hand, the maximal interaction between users and computers. Cognitive issues in the design of intelligent visualization user interface should be studied in order to design the user interfaces that may satisfy variable user requirements. 3.3 Main contents of cognitive research in adaptive cartographic visualization system An exploration of the theory and the method of spatial cognition is one of key technologies in designing adaptive visualization systems, which includes the structuring and the abstraction of human spatial cognition rules and models, the analysis of the characteristics of cognition in map reading, thinking in images and the realization of adaptive visualization system, etc. Studying the functions, the characteristics, the process and the way of map spatial cognition in connection with theoretical models involved in cognitive science will enable us to extract the theory and rules of map spatial cognition which will guide the interface design of an adaptive visualization system. The main contents of cognitive research issues on the adaptive multi-perspective visualization system of spatial information are presented below. 3.3.1 The simulation and the representation of map designer's cognitive activity An adaptive system should have the mechanism with self-description and self-evaluation and the ability of predicting the behavior of system users. Only if a cartographic system has sufficient transparency could it allow the user to have access to the cognitive model of its designer that contains the information about the designer such as his reasoning process, his ability and limit of logical analysis, the interactive functions he thinks are necessary, his design style and his knowledge about the assumed users etc. The model of designer will help users grasp implication of map information, confirm as well as deduce the differences between the user expectation and map author's intent. 3.3.2 The knowledge acquisition of system users and the establishment of user model An adaptive system should have the ability of self-organizing and self-navigating based on the user model. The optimal goal of user simulation is to build an adjustable system, in whi

ch cartographic contents and their interactive functions could be zoomed in or out according to need and map symbol design, the look of system could be dynamically adjusted, and navigation agent could adjust its orientation strategy with the change of users. 4 Experimental methods of electronic map visual cognition Visual cognition experiments with electronic maps constitute an important part of map spatial cognition research. In order to carry out visual cognition experiments in electronic maps, the author has developed a set of experimental systems for the visual cognition test (EMVT) using Visual Basic 5.0. Four visual cognition experiments that explore the way of visual cognition in electronic maps are designed, two of which will be reported in the following sections. 4.1 The flowchart of EPVT The technical process of visual cognition experiment in electronic maps shown in Figure 3 includes creating test maps in raster or in vector format, testing on a computer screen, extracting some records from result database and analyzing test data by a computer and finally displaying analysis results graphically or numerically. Figure 3 The flowchart of EPVT 4.2 The functions of EPVT There are three functions in EPVT - the function of testing on screen, the function of database, and the function of test data analysis and result display. 4.2.1 The function of testing on screen As an electronic map is shown on computer screen, the function of testing on screen is the most important. In order to make comparable between the test data on an electronic map and a print paper map, we use the method of testing on screen for either electronic maps or paper maps. 4.2.2 The function of database The function of database is necessary to automatically analyze test data on a computer screen. It makes easy to manage test data and increases the usefulness of the system. There are two forms of data records in the function of database in this system, one record form is numerical and the other is graphical. 4.2.3 The function of test data analysis and result display This function allows the analyzer to extract the test records from database at will, such as name, date, gender and education, analyze reaction time and radio of correct cognition with probability, process test data in real time and display the experimental results in graphs or digits. 4.3 Experiment design of visual cognition on electronic maps 4.3.1 Experiment 1 (1) Objective Map orientation is an important content in map spatial cognition research. The objective of Experiment 1 was testing the mental process in orientation memorizing cartographic objects by using an electronic map. Since the size and the resolution of computer monitor limits the reading of electronic maps, we have to read an electronic map with the help of functions like scrolling, zooming and querying. The Experiment 1 tries to resolve questions such as whether the way of electronic map reading affects map users ' behavior of memorizing orientation of map and what mental strategies are used by map users in memorizing orientation. (2) Material The map used in Experiment 1 is a topographic map 1:500,000 in vector. The map was modified using MapInfo and Visual Basic. (3) Procedure Subjects were asked to read an instruction at first, attend to the map consciously by following the instruction and keep the map contents in mind as much as possible, then answer the questions. The instruction was " pay attention to the orientation of each settlement on the left map, please press the answer key in toolbox and answer the questions when you think you have memorized the contents on the map. The state will be automatically shifted to answer after four minutes. " When the subject thinks he has memorized the contents of map, he presses " next page " key, then switches the screen to the question window. The program asked the subject to recall the map he just had read and select an answer, each from four choices: which settlement lies in the easternmost, the westernmost, the northernmost, the southernmost on the map? which settlement has the largest size on the map? After selecting the right answers, the subject was told to press the " confirm " key and end the test. The database records correct answers, answers given by the subjects and their reaction times. The result is analyzed statistically which reveals the correctness rate of answers and reaction time. Moreover, subjects are asked to recall the mental strategy used in accomplishing task after the test ends. 4.3.2 Experiment 2 (1) Objective The information processing of spatial relationship is an important content of map spatial cognition experiments. The goal of Experiment 2 is to test the mental actions of subjects in reconstructing spatial relationships among geographic objects from a mental map formed by using electronic map. (2) Material The map used in Experiment 2 is an electronic map in vector. There are four roads, two railways, eight settlements, one reservoir and two rivers on the test map. The test map has basic interactive functions of an electronic map. (3) Procedure The test map was displayed in a graphic frame on a computer screen when Experiment 2 began, the subject was told to read the map using the tools of scrolling, zooming and querying in toolbox on the top of screen. He was then asked to memorize the contents of test map as much as possible. The screen switches automatically to the question window after four minutes. The subjects may also press the answer window, thus switch the screen to the question window. There he was asked to recall the contents of map he had just read and draw all contents of test map as far as he could. In order to make the test simple and effective, the positions of roads, rivers and reservoir on test map fixed, only the initial positions of eight settlements were put on the left and top of screen. In the test, subjects were asked to click the graphics in little circle of settlement using a mouse and drag the graphics to the right position according to his mental map.

The test results from Experiment 2 are recorded in graphics. The answers chosen by the subjects are compared with th e correct answers. Four grades are selected to evaluate them: “completely correct”, “almost correct”, “biased” and “erroneous”. On the basis of all answers of a subject, the system gives five results with “excellent”, “goo d”, “medium”, “pass” and “failed”. 5 Conclusions The applications of computer sciences, multimedia technologie s, Internet and VR in cartography have exerted a great impact on cartography. Cartographic products are extended fro m static maps to interactive maps and 3D maps. Therefore, many problems that had never been considered before occurri ng in digital cartography. Their solutions require a comprehensive study on map spatial cognition. Based on the insig ht gained in information processing, map spatial cognition theory studies systematically the problems such as how a m ap user acquires spatial information from a map, how such information is stored in map user’s mind and how it is ext racted from memory on demand. The adaptive multi-perspective visualization systems of spatial information are a cogni tion-based spatial information visualization system. There is a great deal of cognitive issues that should be taken i nto account, especially concerning the design of the user interface. Cognitive researches need experimental methods. The paper reports the attempt of using experimental methods in cognitive sciences for visual cognition test on electr onic maps. It gives us an impulse for further investigations in map spatial cognition. References Bidoshi K et al., 1 999. Multimedia visualization for maps of the future. In: Proceedings of 19th International Cartographic Conference, Ottawa, Canada. Peterson M, 1994. Cognitive issues in cartographic visualization. In: MacEchren A M, Taylor D R F (ed s.), Visualization in Modern Cartography. Oxford: Pergammon Press Ltd. Fuhrmann S, Kuhn W, 1999. Interface design iss ues for interactive animated maps. In: Proceedings of 19th International Cartographic Conference, Ottawa, Canada. Che n Yufen, 2000. Researches on map spatial cognition theory. Doctoral Thesis, Zhengzhou Institute of Surveying and Mapp ing. (in Chinese) Chen Yufen, 1999. Visual cognition experiments on electronic maps. In: Proceedings of 19th Internat ional Cartographic Conference, Ottawa, Canada.

关键词： spatial information visualization; electronic map; map spatial cognition; visual cognition; cognitive science; visual cognitive experiment

