Chapter 1
Overview

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1.1 Introduction

China is one the first countries in the world to develop map science. Map science is a magnificent part of the history of ancient China. Early Chinese scientists, such as PEI Xiu in the Weijin period (224–273 AD), JIA Dan in the Tang Dynasty (750–805 AD), SHEN Kuo in the Song Dynasty (1031–1095 AD), ZHU Siben in the Yuan Dynasty (1273–1333 AD) and LUO Hongxian in the Ming Dynasty (1504–1564 AD) have made great historical contributions to map science. During the reigns of Emperors Kangxi and Qianlong, China introduced the western scientific mapping method to implement nationwide, large-scale geographic longitude and latitude surveying and mapping of the country.

Through the compilations created by *Huang Yu Quan Lan Tu* (*Map of China in the Emperor Kangxi Reign of Qing Dynasty*) and *Da Qing Hui Dian Yu Tu* (*Map of China in the Emperor Guangxu Reign of Qing Dynasty*), the map science of China was raised to a new level. *Hai Guo Tu Zhi* (*An Illustrated Gazetteer of Maritime Countries*) was compiled by WEI Yuan (1794–1859) in the late Qing Dynasty, and this compilation adapted the geographic latitude and longitude and map projection methods instead of the traditional Chinese method of Ji Li Hua Fang (Drawing Square Grids with Chinese Units of Length "li"). These were creative efforts toward creation of a world atlas in China's map science history.

For decades, from the Qing Dynasty to the period of the Republic of China, topographic map surveying and mapping were conducted intermittently and separately, and only a quarter of the national area of China was covered. Some middle- or small-scale maps and a 1:10 00000 map based on international map subdivisions and other general-purpose maps, as well as general atlases were compiled. Of these compiled

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maps, only the ShenBao Maps published in 1934 had better quality, higher precision, and a more widespread influence. However, in general, China lagged behind developed countries in terms of map science.

The founding of the People's Republic of China in 1949 marked the rebirth of map science in China. At the 60th anniversary of the founding of the People's Republic of China, map science has experienced six decades of magnificent history.

1.2 Development Process

Following the founding of the People's Republic of China, map science development has generally experienced three stages: traditional cartography, digital cartography and cartography informatization.

1.2.1 Formation of Traditional Cartography

In the late 1950s and early 1960s, traditional cartography was formed after more than 10 years of construction and development since new China was founded. The achievements are demonstrated in the following aspects.

1. **Setting up surveying and mapping organizations, agencies and colleges to cultivate talent**

The Military Bureaus of Surveying and Mapping, which are directly under the Ministry of Defense and the State Bureau of Surveying and Mapping, were established for military missions and state affairs in 1950 and 1956, respectively. The People's Liberation Army Academy of Surveying and Mapping was created in 1946 in the liberated areas of northeastern China. In addition, the Wuhan Surveying and Mapping Institute (Wuhan Institute of Surveying and Mapping) was founded in 1956. Cartography majors have been offered in the geography department of Nanjing University since 1957. These institutes have become the training bases for senior technical personnel in the country and military.

2. **The plan for surveying and mapping in China was back on track**

A plan to complete the basic national map was developed based on a uniform geodetic coordinate system (Beijing geodetic coordinate system 1954), a uniform map scale system (the scales of the national map are 1:25,000, 1:50,000, 1:100,000, 1:200,000, 1:500,000 and 1:1,000,000; the scales of the local engineering map are 1:500, 1:1000, 1:5,000 and 1:10,000), a uniform map projection (the Gauss–Krüger projection of 6^0 zones and the Krasovsky ellipsoid were used for map scales from 1:25,000 to 1:500,000; and the Gauss–Krüger projection of three-degree zones for map scales from 1:500 to 1:10,000), a uniform sheet numbering system, and uniform cartographic symbols (including map symbols and map decoration specification). The new topographic maps were uniformly created. The accuracy and artistic quality of the maps obviously improved, and the maps were rich in content. Therefore, these maps could satisfy the requirements of national economic construction, defense construction and scientific research. Furthermore, the technical force grew stronger through these efforts.

3. **Placing more attention on scientific research in cartography and advancement of the mapping industry**

Since many of the issues we face in mapping practice require science and technological solutions, the cartography department at the Zhengzhou Institute of Surveying and Mapping and the Wuhan Institute of Surveying and Mapping attached great importance to scientific research while undertaking the teaching task. Moreover, a cartography research team was set up at the Institute of Geography of the Chinese Academy of Sciences (CAS) in 1954 and expanded to a research office in 1959; in Wuhan city, a surveying and mapping research office was established in 1957 and renamed the Institute of Surveying and Mapping in 1959; and the Institute of Foreign Geographic Name Translation was set up in 1959. There have been an increasing number of scientific researchers committed to cartography. These researchers have obtained a series of theoretical results using a variety of methods and techniques in the discipline of cartography. For example, projection methods were used for the world map, Asia map, China map, China provinces map and China regional map; cartographic generalization, including the map content generalization principle and its methods, map decoration (symbols and indications), and printing of maps (chromium gel image method) has been used, which promoted the development of China's mapping industry. Since then, China began to prepare the 1:1,000,000 scale map, published a 1:4,000,000 Southeast Asian situation map, planned compilation of the National General Atlas of the People's Republic of China, and began to prepare the provinces (autonomous regions) atlas.

4. **Maturation of the internal and external conditions promoted the formation of traditional cartography**

Considering the external conditions, some subjects related to cartography, such as geography, surveying and printing, have become relatively complete theories and technologies, laying a foundation for the formation of traditional cartography. Simultaneously, considering the internal conditions, cartography itself accumulated a rich history in the process of map production over a long period of time. These conditions were summarized and concluded by cartographers from various countries during different phases, which formed the basis for the systemic and complete techniques, methods and theories in map production. Map projection, map compilation, map decoration and map printing, which are the branch disciplines of cartography, have stabilized. Traditional cartography is said to be the accumulation of achievements and scientific summaries of cartography from the late 1950s to the early 1960s.

During this period, cartography was known as traditional cartography, which was defined as the study of the technique, technology and theory of mapping. In terms of mapping theory, the research core included map projection, map generalization, map content representation and symbol systems. These research cores are now known as the three old theories. Map-making technology mainly comprised the compilation manuscript, original printing and map plate-making printing technologies used in the process of map production. In terms of the craft of map-making, map production techniques, especially map printing techniques, were the main methods that were studied. Obviously, the goals of traditional cartography included map-making and product output. In this case, it is appropriate that traditional cartography is defined as “the art, science and technology of map-making”.

1.2.2 From Traditional Cartography to Digital Cartography

Traditional cartography is the basis of map production, and traditional cartography successfully guided map production for more than 10 years following the formation of new China. However, traditional cartography has three obvious flaws. First, traditional cartography gives priority to experience but ignores the construction and research of the basic theory. Second, traditional cartography gives priority to contact with disciplines directly related to the subject itself, ignoring the connection with other higher-level subjects. Third, traditional cartography gives priority to map production but ignores the study of mapping applications, especially research on cognitive activities specific to map makers themselves and laws governing the user’s cognitive activities.

Traditional cartography is said to be a relatively closed system. Thus, it is very difficult or even impossible to obtain substantial progress in cartography. This lack of progress forced cartographers to consider moving out of the closed system of traditional cartography to seek sources of further developing cartography from external systems and a greater hierarchy. All this progress occurred recently in the 1950s after appearance of three scientific systems theories (i.e., information theory, systematicness and cybernetics), and electronic computers were born. This progress not only has decisive significance to the development of modern engineering technology, but once again, this progress also completely changed the scientific landscape of the world and the way contemporary scientists consider the theory of relativity and quantum mechanics. This progress also confirms the direction of cartographic development.

When cartographic scientists realized the defects in traditional cartography and moved out of the traditional closed system of cartography, the next steps were technological revolution and theoretical innovation. These next steps represent the advent of the digital cartography era. The main aspects of this new era are outlined as follows.

1. **Computer technology and electronic publishing technology for maps offer a new means for cartography development**

Abroad, research on computer-aided cartography began in the 1950s, and the research underwent the initial phases of equipment development and software design, as well as advanced stages from experimental trials to more extensive applications in the 1970s. Simultaneously, the cartography research office at the Institute of Geography of the CAS was the first to begin studying computer-aided thematic mapping and computer-aided map plotting based on importing technology, digestion and absorption. The Zhengzhou Institute of Surveying and Mapping appointed selected teachers to Wuhan University and Nanjing University to study electronic computers and computer-aided mapping technology twice in 1972 and 1974, which strengthened the foundation of teaching staff. The institute began to set up a computer mapping laboratory in 1976, they completed China's first computer-aided relief map in 1978, they set up China's first majors of computer mapping and finally began to enroll undergraduates in 1979. Soon afterward, Wuhan Science and Technology University of Surveying and Mapping created the computer-aided mapping major.

Following the 1980s, electronic computers were continually replaced by new computers, some new high-speed and high-precision mapping equipment were applied, and increasing focus was placed on research of computer-aided mapping software. Therefore, the map database was built to meet the needs of large-scale computer-aided mapping. Using a single map database or departmental information system, a multifunctional, multipurpose and comprehensive cartographic information system (CIS) was developed. The electronic publishing system for maps was born in the 1990s. Digital cartographic software based on MicroStation was developed to import hardware at the Zhengzhou Institute of Surveying and Mapping. This software was combined with an electronic publishing system to form an integrated digital cartography and publishing system. This system had become the dominant mode of map production for both the state and military. Integrated digital cartography and publishing systems technology based on computers has replaced traditional manual mapping and publishing technology. Digital cartography extends business through diversification into products, such as digital line graphs (DLGs), digital raster maps (DRGs), digital orthographic maps (DOMs) and digital elevation models (DEMs). All these products became mainstream products, which is a great leap forward in terms of development and an important milestone in cartographic history.

2. **The advancement of cartographic technology requires a new theory**

With cartographic technological progress, especially following the systems theory, cybernetics and theory of transmission, a major problem has been how to combine the systems theory, control theory and the theory of transmission and research cartography as a function of the overall system. In 1969, Kolacny, a cartographer in the Czech Republic, proposed a model for map information transmission systems. As a complete process, this model illustrated the linkage between the map maker and map user. The model caused concern and drew the attention of international academia, including cartographers. Various map information transmission models were proposed. Further research focused on the three transformations (geographic information known by cartographers, maps and geographical environment images converted from map readers) in the process of map information transmission, map information loss and transmission efficiency, which were part of the process of information transmission, controllability of map information transmission and its control process of the control model, and so on. This process reflects all the characteristics of cartography in the information transmission system (Wang and Chen 2000).

What role would a human's cognition play in the process of information transmission? This question is a spatial cognitive theory problem that should be involved in map information transmission and digital information transmission. Cognitive science is a new science that was formally established in 1979. Cognitive science was introduced into cartography, and then, the concept of spatial cognition was put forward by China's scholars at the end of the 1980s and early 1990s. Spatial cognition is thought to be an important area of research in cognitive science. This area of science studies how people understand their existing environment, including related position, spatial distribution, dependencies and the change rules of many factors and phenomena. Studies go further, delving into the structure of the human cognitive system, the spatial cognitive ability of human beings, spatial cognition and mental mapping, and the basic process of mapping spatial cognition, including perception, representation, memory and thinking. The theoretical and practical significance of mapping spatial cognition in cartographic expert systems and geographic information systems (GISs) was revealed (Gao 1991; Wang and Chen 2000).

How can the information transmission of map symbols and their spatial cognitive efficiency be improved? This concept is a matter of applied theory. In 1967, French cartographer Bertin published the book *Graphic Semiotics* and proposed the visual variables of graphic symbols and the theory of visual perception effects for the first time. The six visual variables (shape, size, direction, brightness, density and color) and various visual perception effects (associative perception, ordered perception, quantitative perception, qualitative perception, dynamic perception and stereo perception) have received attention from Chinese cartographers when used in the composition. An experimental method of map perception and map design was studied by Gao (1984). Research and experimentation on map visual perception, especially electronic map visual perception, was also carried out (Chen and Chen 1999). Therefore, theoretical research on map visual perception using digital mapping technology was promoted.

For spatial information transmission in digital cartography, it is necessary to study theories regarding the uncertainties in spatial data and data quality control. Since the mid-1990s, many scholars have focused on spatial data uncertainty factors and forms, the processing method of spatial data uncertainty, the transmission mechanism of spatial data uncertainty in the process of digital cartography, and the method for spatial data quality control. Upon entering the 21st century, a series of theoretical achievements have been made in this research field. For example, the book, *Principles of Spatial Data and Spatial Analyses Uncertainty* (Shi 2005), published by the Science Press in China, comprehensively analyzed the sources of uncertainties in spatial data and spatial analysis. This book deeply addresses the model of spatial data uncertainty, the relation model of uncertainty and the model of spatial analysis uncertainty, visualization of modeling uncertainty and uncertainty of metadata. A doctoral dissertation, 'Research on establishment and application of the DEM precision model' (Wang 2005), brought forward the system contents of DEM error analysis and precision modeling, as well as deeply studying the DEM accuracy evaluation model based on terrain features, the error propagation model of DEM linear modeling, level of detail (LOD) error model and precision evaluations in the cases of 5 terrain types, including loess, hills, middle mountains, mountains and glaciers, and the precision evaluation of a DEM fusion model with features (such as roads and so on). Finally, a DEM accuracy evaluation system was designed, and a prototype was implemented.

3. **The integrated technology of digital cartography and map publishing effectively promotes surveying, mapping production and spatial data infrastructure construction**

The advancement of mapping technology and the deepening of cartographic theory are bound to promote map production development. Since the 1990s, under the guidance of cartographic theory, the integrated technology of digital cartography and map publishing has been used to fulfill the production of national series scale topographic maps and various scales of military collaboration maps, joint operations maps, aeronautical charts and nautical charts. This integrated technology was also used to design, compile and publish a 1:3,000,000 Geography Map of the People's Republic of China, a 1:5,000,000 World Geography Map, the National Atlas of the People's Republic of China, the National Economic Atlas, the Population Atlas of China, the Atlas of Chinese War History, the Atlas of the Jiangsu Province, the Atlas of the Zhejiang Province, the Atlas of the Jiangxi Province, the Atlas of the Xinjiang Uygur Autonomous Region, the Atlas of Chongqing city and atlases for other provinces and cities. The richness of these products in terms of contents, novel expressions, fine graphic lines and beautiful printing is like nothing that has been previously seen. These maps reflect the unity of scientific character, artistic quality and practicality. Simultaneously, 1:50,000 1:250,000, 1:50, 1:1,000,000 scales of the cartographic database of China, 1:3,000,000 cartographic databases of the Chinese mainland and its surrounding areas, 1:5,000,000 and 1:14,000,000 global map databases, marine surveying and mapping databases, and digital DOM databases were also established. Thus, a preliminary framework of Chinese and global spatial data infrastructure was constructed.

With the development of computer-aided cartographic and spatial database technology and the establishment of various databases, professional electronic maps (atlases), multimedia maps, online maps, electronic navigation maps, and other mobile navigation maps, the visualization system emerged at a historic moment. Other high-level applications are also popular, such as navigation electronic maps (Beijing Four Dimensional Graphical Navigation Information Technology Co., LTD., China Map Publishing House) and China Electronic Maps (Beijing Lingtu Software Technology Co., LTD., People's Traffic Video Electronic Publishing House).

1.2.3 The Concept of Cartography Informatization Is Proposed

Technically speaking, digital cartography hit a large milestone. However, the concept of traditional cartography remained limited.

There are also three obvious flaws in digital cartography. First, it has been a closed system in a digital environment, as the final goals are digital map production and output, and the production process of digital cartography is an isolated system. Second, digital cartography attaches significant importance to digital mapping technology research and ignores the independent innovation of digital cartographic theory research. Many theories also remain regarding the terms and concepts of digital cartography, as there is a lack of in-depth discussions, experimental demonstrations and actual applications. Third, prioritizing the products of digital maps still ignores application services, especially research on comprehensive application services.

Therefore, we have three basic understandings of digital cartography. First, digital cartography was developed in the late 1970s and early 1980s, so the history of digital cartography is just over 30 years. Changing the technique from manual mapping to digital mapping, which laid a foundation to further develop cartography in the information age, is a significant milestone. Second, traditional cartography has formed an adapted basic theory after a long period of information precipitation and accumulation. However, due to the relative youth of digital cartography, it has not yet formed its own basic theoretical systems that are both inherited and innovative. Third, digital development is only the instrument, and digital, information and knowledge services are the real objectives of development. It is well known that informatization and digitization are not entirely separate: if there is no digitization, there can be no informatization. Cartography informatization will extend and deepen digital cartography.

The only way to move out of digital cartography seems to be through cartography informatization. That is, the path forward must move out the closed system of digital cartography and seek continued development of the deep structure of the outside system. This path is considered to be the 'data-information-knowledge' process. Continually extending, expanding and deepening informatization and knowledge will aid in the arrival of the cartography information era. The main features are as follows.

1. **The focus of cartography has been transferred from information acquisition to intensive information processing**

Chen (1991), a member from the CAS, pointed out that the primary problem in developing cartography is the profound issue of map information. Map workers have made great efforts toward solving this issue. Map workers have even applied virtual contours, interpolation isotherms and derived boundary methods to supplement the information.

The satellite remote sensing technology that was developed in the 1960s has become the major technical means for collecting Earth observation data. After entering the 1990s, Earth observation data collection has advanced in the direction of multisensor, high-resolution and multitemporal remote sensing. Remote sensing information has become the main information source of cartography. Additionally, satellite navigation and positioning systems that can provide precise, all-weather, real-time, worldwide information completely meet the requirements of mapping and enable updating of large-, medium- and small-scale maps. Currently, driven by the integration of Earth observation information collection, processing and service, it is not only possible to transfer the focus of cartography from information collection to intensive information processing but it also necessary. This process has three main aspects.

(1) **The improvement of the cartography modeling method-Intelligent spatial data processing toward cartographic generalization**

Cartographic generalization is the most challenging and creative research field in cartography. Since the 1950s, as the focus of cartography has gradually shifted, and the field has received increasing attention. Cartography has evolved from the process of qualitative description to quantitative expression, from manual methods to automatic cartographic generalization based on modeling, algorithms and knowledge, and from the goal of fully automated cartographic generalization to human-machine cooperation. Automatic cartographic generalization has progressed from experiments with single features and separate models or algorithms to a whole process (all elements, the entire process and controllable) with process control and quality evaluation. In other words, cartography has undergone an evolution from simple to complicated, from part to whole and from digital to intelligent. Therefore, cartography already has the basic conditions for engineering and industrialization in the process and quality control system of automatic cartographic generalization (Wang 2008a, b).

Corresponding books have been published in different periods, such as the Chinese translation of *Mathematical Statistical Method in Map-Making* (Bocalov, an original author from the former Soviet Union), *Cartographic Generalization* (original author Topfer Germany, 1982), *Modeling Method of Cartographic Data Processing* (Wang and Zou 1992), *Mathematical Methods of General Cartography* (Zhu and Xu 1990), *Principles and Methods for Automatic Generalization of Digital Maps* (Wang and Wu 1998), *Multiscale Spatial Data Representation and Automatic Generalization* (Wu 2003), *Basic Theory and Technology of Map Generalization* (Wu 2004), *Spatial Information Intelligent Processing Methods for Map Generalization* (Wu et al. 2008a), and so on.

(2) **Deepening of the cartographic analysis function-Spatial data mining and knowledge discovery (SDMKD)**

In the traditional cartography era, acquiring knowledge from a map involves visual readings, measurements, calculations, analyses and deductions. With the advent of computers for digital mapping and GISs, measurements, calculations and analyses can be realized by computers. Spatial analysis has become the main function of GISs. However, the level of accessible knowledge is only surficial or shallow in the two cases above. Spatial data mining and knowledge discovery (SDMKD) is a highly attractive and challenging research area for humans facing the problem of processing large amounts of data. SDMKD is the key to transforming data into information and furthering knowledge. SDMKD is a nontrivial process that distinguishes effective, innovative and potentially useful and ultimately understandable patterns from the amounts of data. The purpose of SDMKD is to support spatial decision-making. The complexity and challenge of solving the problem has drawn increasing attention from Chinese scholars. Among the research, '*Theory and Application of Spatial Data Mining*' (Li et al. 2006) is the most representative academic work and basically reflects the research of this field in China. The project *Spatial Data Mining Technique and Application Engineering* (Liu et al.) won the first prize in science and technology progress issued by the Chinese Association of Surveying and Mapping in 2008. In addition, several research projects have been conducted. For example, 'spatial clustering analysis with obstacle constraints based on swarm intelligence' (Zhang 2007), 'spatial data mining of space discrete points' (Wang 2008a, b), 'spatial data mining based on fuzzy association rules' (Xiong et al. 2005), and so on. Some studies have made significant progress. These include 'SDMKD' from the Innovation Project of the CAS and 'Research on spatial data online analysis and spatial data mining' from the Open Fund Project of Visual and Auditory Information Processing State Key Laboratory. SDMKD will lead to the emergence of a wide variety of knowledge maps. These maps would greatly enrich the varieties and content of thematic maps and make map services seem more targeted and more human.

(3) **Map services become even more prominent**

The essence of cartography informatization is service. In the guiding ideology, geospatial information service is the goal. On the technical side of the network service, geographic spatial information services apply web service/grid service, popularization and universal service based on open standards and protocols. Product applications have the characteristics of various service modes, such as paper map services, digital map services, electronic map services, location-based services, embedded web services and network map services. These product applications have made good achievements over the years.

2. **Expansion and extension of the cartographic function—geographic information systems**

Before computers existed, people mainly used paper maps, series maps and atlases to obtain geographic knowledge, and many types of measurements and analyses have made on these maps. The previous maps, series maps, and atlases together can be regarded as non-computerized (contents are solidified) GISs. Since the wide use of computers began, especially the development of computer-aided cartographic technology and map database technology, people have attempted to employ special tools to collect, store, manage, analyze and use geospatial information. These attempts led to the introduction, development and application of GISs in the late 1970s and early 1980s. Although China lagged behind more developed countries by more than 10 years, GISs rapidly developed (Wang 2008a, b). More than 30 years have passed, and GIS software has made significant progress in China through the introduction of foreign advanced software (ArcInfo, MapInfo, and so on) to the independent development of software (such as MapGIS, SuperMap, GeoStar and military geographic information systems (MGISs)). GISs have been used in a wide range of fields, including resource management, urban planning and management, intelligent transport, environmental monitoring and management. GISs have become the foundational platforms to support the construction of digital cities, digital provinces and autonomous regions, digital China, digital rivers, digital oceans, and digital Earth. The software architecture of a GIS extends from the stand-alone version (fragmented information silo) to the network version. In the network environment, great changes have also taken place in the architecture of GISs, developed from host-based GIS, desktop GIS, web GIS, distributed GIS (DGIS) and open GIS (OpenGIS). The development mode of GIS software went from feature pack to integrations, modules, and components. GIS functions advanced from management to analysis and further to decision-making support. Research on digital terrain analysis (Zhou and Liu 2006) and spatial analysis modeling (Zhu and Shi 2006) deepened and became more practical. In particular, the publishing of a series of teaching books on GISs from Nanjing Normal University marked the overall great progress in GIS theories, methods and technologies.

Currently, Chinese educational and industrial communities focus on the key techniques of geospatial information sharing and spatial data interoperability based on web services and resource sharing and cooperation based on grid services.

Under the financial aid of the National Science-Technology Support Plan Projects and the National ‘863’ Project, practical results have been obtained in realizing geospatial information sharing and spatial data interoperability based on web services. Web services can support different protocols and data formats, such as the simple object access protocol (SOAP), web services description language (WSDL) and unified description and integration (UDDI) protocol. The key information resource sharing technologies and functional corporations based on grid services have made some progress.

GIS functions and data are distributed and heterogeneous in a grid environment. Data access and integration, as well as service migration/composition based on user requests on a one-stop service system will become a new model of geospatial information service. Thus, the user can enjoy the service without the need to acquire data. The internally tightly coupled GIS software does not need to be installed, and the user can enjoy the GIS function service.

3. **The new growth point of geography—spatial information visualization and the virtual geographic environment**

Originally, the map was a visual product. So-called visualization refers to applying computer image processing technology to graphically display the complex scientific phenomena and the natural landscape, as well as very abstract concepts that were studied to understand the phenomenon, discover laws and spread knowledge.

The application of visualization theory and technology in cartography began worldwide in early 1993. This application mainly explores how to effectively apply theory and technology to spatial data visualization in the field of computer graphics. For GISs, visualization technology has been far beyond the scope and level of traditional symbolic representation and visual variable notation. We have entered a stage to explore the visual effect and the function of the visual tools under the conditions of a dynamic environment, temporal-spatial transformations, and multidimensional, interactive maps. More importantly, visualization is a kind of spatial cognition behavior. While providing insight into the complex process of spatial data analysis and displaying the multidimensional and multitemporal data and process, visualization can effectively improve and enhance the capacity of geographical environment information transmission and aid in understanding and finding the relationship between natural phenomena and cultivating the ability of a human's imagery thinking.

Virtual reality (VR) technology is, in fact, the most effective application of visualization technology; the purpose is to construct a virtual geographical environment.

The research field in China began in the mid-1990s, starting with a study of 3D terrain visualization (Xu 1990; Gao et al. 1999). Later, research more often involves using 3DS animation to observe the Earth's surface along the preset path, interactively using OpenGL software on a computer or workstation to observe a three-dimensional virtual terrain simulation in real time, using the Performer and MultiGen (three-dimensional modeling software) in the SGL workstation to accomplish Earth surface modeling and real-time display, or applying VRML (virtual reality modeling language) to spread virtual landscape information on the Internet. Upon entering the 21st century, VR technology has developed toward being more universal and practical. In recent years, spatial information visualization software has emerged endlessly but has been increasingly integrated with GIS applications. These technologies can be divided into two kinds, i.e., digital map browsing software and commercial game software. The former focuses on scheduling and rendering of large-scale geographic data. Data are usually in distributed storage on a different server and should be transmitted to the client through the network by using a special caching mechanism to increase the speed of browsing for the client. The latter focuses on the rendering of small-scale geospatial data to achieve very realistic effects by making full use of the new functions of graphics hardware. Therefore, spatial information visualization and VR technology have increased interests in geographical environment information based on graphs and pictures. Globally integrated and multiresolution 3D visualization human-machine interfaces have become the default mode for people to understand the geographical environment.

4. **Deepening cartographic theory—cartography informatization requires a scientific theoretical system**

Cartography informatization involves inheritance and development based on traditional cartography and digital cartography. The scientific theoretical system of cartography informatization should certainly include the deepening and upgrading of traditional cartography and digital cartography theory.

Cartography informatization is a new definition that has been widely discussed in recent years. Why on Earth should we put forward cartography informatization? What is cartography informatization? What is the relationship between cartography informatization and traditional cartography, as well as digital cartography? How can a cartography informatization discipline system be built, including a theoretical system? Such problems have been put forward but have not received in-depth study, although they draw higher attention from academic circles.

In China, the State Bureau of Surveying and Mapping and the Institute of Surveying and Mapping have organized a conference on informatization surveying and mapping systems. *'Proceedings of Informatization Surveying and Mapping'* was published by the Surveying and Mapping Press in 2008 with funding from the Book Publishing Foundation of Surveying and Mapping Science and Technology. Among these publications, 'On informatization characteristics of cartography and the idea of the theory and technology system' (Wang 2008a, b) explores the formation, development conditions, contents and features of cartography informatization, as well as proposes a theory system and technical system and discusses the key research issues. This publication was based on the individual analysis of traditional cartography and digital cartography according to their formation conditions, research object and features, defects and the way toward further development. 'The characteristics of basic geographic information service and related strategy in the new period' (Zhou and Liu 2008) suggests that along with the advancement of basic geographic informatization, the basic geographic information service constantly reflects the new characteristics of the information age, including diversification of basic geographic information products, network services, personalized information services, public services, and collaborative services.

Cartography informatization requires construction of a scientific system of its own, but this task is a long-term undertaking, and the current study is only the beginning of this undertaking.

1.3 Main Research Achievements

1.3.1 Cartography and Map Publishing Technology Fully Realizes Digitalization and Integration

The development of computer technology has brought a large revolution to cartography technology. Equipment development and software design for computer-aided mapping began in the 1970s in China. In the late 1980s, a computer-aided mapping software system was developed. In 1991, China's first set of practical color map publishing systems were created. Computer-aided cartography completely changed the status of the difficult and complicated manual mapping that had lasted for one thousand years. Map printing and publishing progressed from wet photomechanical reproduction and dry plate photography technology to digital photography. Color separation technology was extended from manual techniques to color separation photography and color separation software. Graphic layout and large version imposition technology advanced from manual methods to computer processing. Screening technology developed from amplitude modulation screening and frequency modulation screening to hybrid screening technology. Plate-making technology developed from the photographic transfer process and film printing to computer (digital)-to-plate. Proofing technology developed from artificial overprint proofing, film proofing and chemical proofing to digital proofing. Printing techniques developed from lithographic printing and offset printing to digital printing (computer to print). Printing process management developed from independent process management to digital whole process management. Since the 1990s, map production has fully implemented the transformation from manual simulation methods to computerization and digitalization methods. Digital and integrated mapping and publishing technology has become a basic technology for map production. Especially when combined with GISs, databases and remote sensing technology, map production efficiency is significantly improved, map content is enriched, map varieties are increased, and map currency is enhanced. Digital and integrated mapping and publishing technology is universally used in the production of the National Series Scale Topographic Map, Great National Atlas, Atlas of Provinces (Autonomous Regions, Municipalities), and all kinds of thematic maps (atlas). This technology is a milestone in map production in China (Wang and Wu 1998).

1.3.2 Implementation of National Basic-Scale Topographic Map Coverage and Preliminary Completion of the Basic Geographical Spatial Database for China and Worldwide

Surveying for China's 1:50,000 topographic maps began in 1951, and nationwide large-scale surveying began in 1956. Surveying and updating have been carried out simultaneously since 1964. By 2003, the 1:50,000 topographic maps covered an area of 760 square kilometers. In 2006, we started a project called the '1:50,000 National Topographic Mapping for the Blank Area of Western China', covering an area of 260 square kilometers. By 2010, 1:50,000 topographic maps had fully covered China's land area. Topographic map surveying began at a scale of 1:1,000,000 in 1978. This map is one of the major basic-scale topographic maps for provinces (or autonomous regions and municipalities) and basically covers the main grain and cash crop production regions in the plains and hills. The 1:5,000, 1:2,000 and larger-scale topographic maps basically cover China's urban areas (Tang 2003). The 1:1,000,000, 1:500,000, 1:250,000 and 1:100,000 topographic maps covered all of China's land area. Computer-aided mapping and database technology are used to build all kinds of geospatial databases, such as 1:1,000,000-, 1:500,000-, 1:250,000- and 1:50,000-scale basic geospatial databases, multiscale marine surveying and mapping databases and aviation chart databases; 1:3,000,000 scale databases of China and neighboring countries; 1:5,000,000-scale world map databases; large-scale DOM databases; 1:10,000-scale provincial (or autonomous region and municipalities level) databases; and finally, large-scale urban geospatial information databases that are under construction (Cui 2007). The success of the large digital engineering construction project has laid a solid foundation for China's geospatial data framework, including digital Earth, digital China, digital provinces and autonomous regions, digital cities, digital rivers, digital oceans, and so on. This database can provide reliable and timely spatial data for national and regional economic planning, disaster prevention and mitigation, irrigation construction, post-disaster reconstruction, design and construction of major projects, digital battlefield construction, development of information weapons and equipment, command automation systems, and so on.

1.3.3 Studies on Automatic Generalization of Geospatial Data Have Achieved Substantial Breakthroughs and Developments

As the most challenging and creative research area of cartography and geographic information engineering, cartographic generalization studies have always received close attention from scholars both at home and abroad.

In the 1950s, China began investigating the basic theory, method and specific application of cartographic generalization. A method to determine the cartographic generalization index with mathematical statistics was explored in the 1970s (Fan 1978). The emphasis was placed on the model and algorithm of cartographic generalization, human-machine cooperation and expert systems, and the relationship between them in the 1990s (Peng 1998). Since entering the 21st century, researchers have focused on all elements and whole process methods of automatic cartographic generalization based on algorithms, models and knowledge, especially those dedicated to intelligent cartographic generalization and automatic generalization process control and quality evaluation based on cartographic generalization chains. Substantial breakthroughs have been made. After decades of study, cartographic generalization has developed from a subjective process to an objective scientific method, from a qualitative description to a quantitative description, from a cartographic model to an automatic generalization based on an algorithm, model and knowledge, and from the pursuit of fully automated generalization to the realization of human-computer interaction and collaboration. The change from the automatic generalization test of a single feature to the automatic generalization of the whole (i.e., all features, entire process and controllable) with process control and quality design has been profound. In addition, this progress has basically established the system of theory, method and technology for spatial data automatic generalization. The research results reached an international advanced level. It is very helpful to simulate the human being's mode of thinking in the process of cartographic generalization with computers. Additionally, it objectively and correctly reflects the characteristics of map information processing by human beings or with computers and will realize optimal human-machine collaboration (Wang 2008a, b). The research achievements of automatic cartography generalization laid a solid foundation of theories, methods and techniques for using large-scale digital map data to produce smaller-scale maps and for automatic derivation of multiscale spatial databases based on large-scale databases and all-in-one updates, as well as multiscale spatial data representation in GIS.

1.3.4 The Compilation and Publishing of the Great National Atlas, Regional Atlases and All Kinds of Thematic Atlases Has Become a Monument in Cartographic History

The compilation and publishing of the atlas is one of the landmark projects of the cartography and geographic information engineering disciplines.

The Great National Atlas of China is a national key scientific research project approved by China's state council in the early 1980s. Five volumes, including general, natural, agricultural, economic and historical atlases, have been published. Among them, the National Agricultural Atlas was first published in 1990, the National Economic Atlas was published in Chinese and English versions at the same time in 1993 and in an electronic (CD-ROM) edition in 1995, the National General Atlas was published in 1995 and an electronic version (CD-ROM) was released in 1997, the National Natural Atlas was published in Chinese and English versions at the same time in 1998 and an electronic version (CD-ROM) was released in 2006, and the National Historical Atlas was divided into three copies and was scheduled for publishing beginning in 2009. Five volumes of the Great National Atlas of China as a whole are the complete assembly of the Chinese natural, economic, social and historical factors. These five volumes are an overview and summary of the research achievements of China in the field of geosciences, biological systems, environmental science, economics and history. These atlases not only provide an important scientific basis for the overall planning and macroscopic decision-making of China's economic construction and social development but also provide accurate maps and abundant materials for scientific research and teaching. These maps drove the publishing of all kinds of regional atlases and thematic atlases in China. The release of the provincial (autonomous region, municipalities) atlas and the corresponding electronic (CD-ROM) version have been pushed to a new pinnacle. The map data of all thematic atlases are richer. Among the provincial (autonomous region, municipalities) atlases, the Atlas of the Jiangsu Province, the Atlas of the Zhejiang Province, the Atlas of the Jiangxi Province, the Atlas of the Jilin Province, the Atlas of the Xinjiang Uyghur Autonomous Region, the Atlas of the Chongqing Municipality, etc., belong to typical works because of their advanced design concepts, selected contents and expression methods, and high levels of printing and binding quality. The Atlas of Shenzhen was awarded the only 'Cartography Award for Outstanding Achievement' at the 19th International Cartography Association conference. Many thematic atlases have outstanding features, such as the Atlas of Chinese Warfare History, the Atlas for the Natural Protection in China, the Atlas of China's Population, the Administrative Division Atlas of the People's Republic of China, the Standard Atlas of Geographic Names of Administrative Zones of the People's Republic of China, the Atlas of Remote Sensing Monitoring of Land Resources and Ecological Environment Around Beijing, the Atlas for the New Beijing Great Olympics, the Atlas for the Wenchuan Earthquake Disaster, and all kinds of image atlases of cities. All kinds of electronic maps, multimedia electronic maps, network electronic maps and mobile navigation electronic maps emerged at the right moment for specialized applications. The user scope is more popular. In particular, to celebrate the 60th anniversary of the founding of the People's Republic of China, a series of large atlases for China's different provinces have been edited and published for the first time. The total is 34 copies, one for each province (autonomous regions, municipalities and special administrative regions). Compiling and publishing the Great National Atlas, the Regional Atlases of China and the thematic maps and atlases is a milestone in the development history of cartography in China and has become one of the symbols of our age.

1.3.5 Evolutionary Process of Geographic Information System Software from Imports to Domestic Self-development

GIS is the development and extension of cartographic function. GIS is the result of computer-aided mapping and mapping databases but is beyond them. GISs in China started in the 1980s and originally imported foreign software (such as Arc Info) to construct application systems. Then, we worked on domestic software step-by-step and published the first teaching materials on GISs (Huang and Tang 1990). The software rapidly developed in the 1990s, and domestic GIS software was put into use. Since entering the 21st century, GIS software products have greatly increased. This evolution started with an integrated GIS basic software platform and grew to present a series of GIS software products, including basic platform software, special tool software and application software. The typical software products are MapGIS series software, SuperMap series software, GeoStar series software, and military and other special series of GIS software. This software has been widely used in many fields, including resources, environment, traffic, communication, energy, agriculture, forestry, water conservancy, defense, public security and aerospace, digital provinces, digital cities, digital rivers and oceans, and other fields. At the same time, a large amount of teaching materials on GISs have been published (Wang 2001). With the rapid development of computer network technology, GIS has changed from the traditional stand-alone version to the network version. The application of GIS expanded to all areas and broad geographic areas; there were many different types of distributed and heterogeneous GISs. These GISs were created and maintained using different software platforms or database systems according to the application requirements from different business organizations, governments, enterprises and individuals. According to this pattern, every user of a GIS needs to build a large database and install the complete and tightly coupled functions of GIS software and have his/her own spatial data storage and processing equipment. This requirement will result in redundant construction and considerable waste of information, storage and calculation resources, leading to spatial data inconsistencies and influencing the effect of spatial analysis and decision-making support. In addition, the unshared information and isolated system will make it difficult to solve important and complex problems involving many domains and multidisciplinary departments (Wang 2009). The emergence of web services and grid service technology provides beneficial conditions for solutions to the above problems. These technologies laid a solid foundation to realize geospatial information sharing and spatial data interoperability based on web services and further information resource sharing and problem solving in a dynamic and collaborative environment based on grid services. The research of GridGIS has recently received more attention.

GridGIS has been developed under the Chinese High-tech R&D (863) Program and National Science and Technology Support Plan during the state 10th five-year plan and the state 11th five-year plan, mainly focused on solving two problems: first, how to realize the connectivity and interoperability among legacy (existing) systems in grid environments, and second, how to build a new system according to the requirements of deployment models, development models, running modes and service modes in the grid environments (Wang 2009). In recent years, research in this field has made rewarding progress in China.

1.3.6 Generalization and Practical Application of Spatial Information Visualization and Virtual Geographic Environment Technology

Spatial information visualization and virtual geographic environment technology is a new and growing part of cartography. China's earliest spatial information visualization research was used in 3D terrain visualization (Xu 1990). Later, many people used the existing graphics software and animation software to produce geospatial information visualization products, for example, using the 3DMAX animation to obtain geospatial observations along a specific path, using OpenGL software to realize real-time interaction and stereoscopic observation of three-dimensional terrain simulation in computers or workstations, using Performer and MultiGen (three-dimensional modeling software) to complete geospatial modeling and real-time display on the SGI workstation (Liao 1996), and so on. Developed on the basis of spatial information visualization technology, the virtual geographical environment is a kind of advanced human-computer interaction system generated by computers. This environment is a cognitive environment based on visual perception, including hearing, touch and smell. This environment enables a person to engage with a world based on computer graphics, and this environment is created by a head-mounted 3D solid displayer, data glove and stereo earphone, giving a person an immersive feeling by implementing observation, touching, and detection tests (Gao et al. 1999). Of course, such equipment is expensive. Only a few famous universities in our country have this technology at present. Therefore, the application range of this technology is limited. At present, research on spatial information visualization and virtual geographic environment technology mainly focuses on three aspects: digital Earth browser software, distributed virtual geographic environment platforms, and integration with GIS and its practical application. Digital Earth browser software such as foreign Google Earth, World Wind, Skyline, Earth Viewer 3D, Arc Globe, etc., and domestic Geo Globe focus on large-scale geospatial data (terrain, texture, border, node, and 3D building model) scheduling and rendering. Data are usually in distributed storage on a different server and must be transferred to the client through the network using a special cache mechanism to increase the speed of browsing on the client's end.

Virtual geographic environment platforms use high-level architecture (HLA), for example, to build a distributed virtual geographic environment (DVGE) system framework (Xu et al. 2005). The integration of GIS and virtual geographic environment technology is a trend. Therefore, we can fully utilize both the multidimensional dynamic expression ability of virtual geographic environment technology and the advantages of GIS data processing and spatial analysis. Currently, there are primary products from virtual geographic information systems (VGISs). The theoretical study of virtual geographic environments has made many accomplishments (Su and Sheng 1997).

1.3.7 Spatial Data Mining and Knowledge Discovery Are Already Becoming Practical from Theoretical Research

SDMKD is a nontrivial process that distinguishes or extracts effective, innovative, potentially useful, and ultimately understandable patterns (knowledge) from massive spatial datasets. Traditional map application and analysis acquires knowledge and rules of the geographical environment through visual reading and simple measurement. SDMKD is largely limited by a person's knowledge and experience and the measurement tool and method. Spatial analysis of GIS mainly involves performing graphics operations. The functions of extracting and finding useful information and knowledge hidden in massive amounts of geospatial data are still relatively weak. Therefore, SDMKD is the development of a traditional map application and analysis in the digital map environment and the extension and deepening of the GIS spatial analysis function. SDMKD adapts to the developing trends and needs of information-age cartography that emphasize information processing rather than information acquisition. SDMKD studies have only been conducted in our country in the last 10 years. However, the studies on processing models and spatial analysis of mapping data in the 1980s–1990s, i.e., the basic modeling schema of 'Data Preprocessing-Design and Building of Digital Model-Data Processing-Design and Building of Map Model-Interpretation and Application of Map Model', can be seen as the primary research results of SDMKD (Wang et al. 1992). In the late 1990s, especially since the turn of the century, SDMKD research showed the following characteristics (Wang et al. 2006; Bi et al. 2008). First, a series of theoretical successes have been obtained. One of the most representative works is the *Spatial Data Ming and Application* by Di (2000). In detail, the book discussed the space data cleaning, available theory and method of spatial data mining, spatial statistical analysis theory of image texture, geo-rough space, cloud model, data field, spatial data mining based on the concept lattice, landslide detection and data mining, spatial data mining based on the inductive learning and rough set, spatial clustering and knowledge mining, image mining based on spatial statistics, and so on. Meanwhile, the development of a spatial data mining system was introduced. Second, spatial analysis combined with spatial data mining and knowledge discovery broadened the research perspective of SDMKD (Chen et al. 2003). Both methods have the advantage of GIS spatial data management and processing and enrich the function of GIS. Third, SDMKD research is becoming increasingly practical. Some application results were obtained; one of the most representative results is using spatial data mining technology for data integration, analysis, evaluation and optimization, and decision-making support in the field of sustainable land use and management.

1.3.8 Spatial Data Uncertainty and Quality Control Research Have Made Significant Progress

The concept of spatial data uncertainty is more generalized than the measurement error. Measurement error processing already has a set of mature theories and methods. With the wide application of GISs developed on the basis of computer-aided mapping and map databases, the error in the spatial data is not only from the process of surveying and mapping but also exists in the whole process of GIS information acquisition, collection, storage, processing, analysis and application. Hence, studying the cause of GIS spatial data uncertainty and its performance, handling method and transmission mechanism has received much attention. The research in China began in the mid-1990s and has reached its highest level since entering the new century (Guo et al. 2003). For a period of time, the research mainly focused on three basic theoretical questions. First, the confidence region of the basic geometric elements of the spatial data was analyzed. That study mainly considered the confidence region of point, line and multilateral (surface), which are the most basic geometric elements of GIS spatial data. Among these elements, the confidence region of the point is the key. Starting from the perspective of the error ellipse, an oval confidence region is given for the point, and then, confidence regions consist of ellipse and line segments for the established line segment and polygon (Guo et al. 2006). Second, the position uncertainty was considered by taking spatial data elements as a whole. That is, the ‘ε-band’ width was determined according to the average information entropy of the marginal distribution of all linear elements and then extended to the error entropy donut of the surface elements. Third, the statistic measurement model of the disfigurement rate of attribute data accuracy in GIS was researched. The stratified (data layer) sampling method was used to investigate the disfigurement rate model of the attribute data, and then, the accuracy of attribute data was measured through the disfigurement rate model. There are several representative research results in this field. The *Principles of Spatial Data and Spatial Analyses Uncertainty* (Shi 2005) comprehensively analyzed the sources of uncertainty in spatial data and spatial analysis. That study deeply addressed the model of spatial data uncertainty, the relation model of uncertainty and the model of spatial analysis uncertainty, the visualization of modeling uncertainty and the uncertainty of metadata, the theory of uncertainty and its applications in spatial data mining and cadastral data quality control. In addition, we propose a GIS data quality information service system based on web services. The thesis ‘Research on establishment and application of DEM precision model’ (Wang and Zhu 2005) put forward the content system of DEM error analysis and the precision model with the aim to address the existing problems; this thesis deeply studied the DEM accuracy evaluation model based on terrain features, the error propagation model of DEM linear modeling, the LOD error model and precision evaluation in the case of 5 types of terrain, including loess, hills, middle mountains, mountains and glaciers, and the precision evaluation of a fusion model of a DEM with features (such as roads, etc.). Finally, a DEM accuracy evaluation system was designed, and a prototype was implemented. In particular, the application of the space data uncertainty theory to quality control and evaluation in spatial data production has made many accomplishments in recent years and played an important role in ensuring the reliability of spatial data applications (Wu et al. 2008b).

1.3.9 Theoretical Research of Cartography and Geographic Information Engineering Changes from Traditional to Modernized

Cartography theory has always been widely considered by China's cartographic academia and industry. In the era of traditional cartography, cartography theory studies have focused on three aspects (Wang 2001), i.e., map projection, cartographic generalization and map symbol (representation). Among them, map projection is the mathematical foundation of a map. Zhou proposed a new map projection theory with a distortion ellipse by successfully applying a mathematics method (Zhou 1957). FANG explored new map projection methods according to Zhou's theory and designed many new map projections (Fang 1983). Cartographic generalization is a perpetual subject of cartography. Cartographic generalization mainly studies the basic principles and methods of cartographic generalization and how to determine the generalization index by using mathematical statistics, as well as its applications (Gao and Zhang 1965). The map symbol is the most basic expression form of a map. The map symbol mainly includes studies of the rule of symbol composition and other design issues. Map projection, cartographic generalization and map symbols are commonly known as the 'old three theory' of traditional cartography. In the era of digital cartography, using computers, it is easy to solve new projection design and calculation problems that could not be solved with a slide rule or hand-operated calculator in the past. Hence, new map projections emerge endlessly. The mathematical foundation of the map can be established through computer drawing. Map projection transformation among various map projections can also be implemented by a computer. Principles of *Mathematical Cartography and Map Projection Transformation Principles and Methods* (Yang et al. 2000) was the masterpiece in terms of research results at that time. That study was generally acknowledged as leading at the international level and became the pride of China's cartographic community. From cartographic generalization research came the emergence of the quantifiable generalization index and mathematical generalization methods. Mathematical methods, such as mathematical statistics, graph theory, fuzzy theory, neural networks, fractal theory and mathematical morphology, are widely used in the single feature of computer cartographic generalization. Theoretical research has been conducted and summarized (Wang 2001). The map symbol function emphatically studies graphic visual variables and the visual perception effect and its applications in map design (Chen 1996; Liao 2007). On this basis, theoretical research on the geographic information transmission mode, cartographic model and map spatial cognition was carried out. After entering the 21st century, the concept of cartography informatization was put forward.

The theories and methods of map projection transformation have matured and are widely used in map production (atlas). Cartographic generalization theory focuses on intelligent process control and quality evaluation with characteristics of all its features, the entire process and controllability. As a map language, map symbol systems study sentence, semantic and pragmatic rules. The 'old three theory' is reborn. Based on multimode spatial-temporal integrated cognition theory developed for maps, GISs and virtual geographic environments and by taking the spatial information transmission process (including information acquisition, processing and services) as an integrated system, a theory system including map models, visual perception, geographic ontology and spatial reasoning methods has been formed. This formation marked the progress of theoretical research and the great advancements of engineering technology in the cartography and geographic information engineering disciplines.

1.3.10 The Discipline and Professional Education Have Formed a Complete System and Entered the Key National Disciplines

The cartographic education career of new China can be traced to the northeast School of Surveying and Mapping in 1946, which existed before the national liberation. In 1952, this school was moved to Beijing and its name was changed to the Institute of Surveying and Mapping. The Wuhan Surveying and Mapping Institute (Wuhan Institute of Surveying and Mapping) was founded in 1956 by the local government. Since then, the cartographic discipline and major housed by the above two schools have been officially listed in the national higher education system. Thus, the preliminary development stage of the cartographic discipline and major occurred in the 1950s and 1960s, the adjustment and development stage took place in the 1970s and 1980s, and the rapid development stage occurred in the 1990s. At present, the discipline and major education system of cartography and geographic information engineering (engineering) or cartography and GISs (science) in China is complete. These educational disciplines entered the national key disciplines and formed a complete education training system that includes secondary school students, undergraduates and master's and doctoral students who are distributed in surveying and mapping engineering, geology and mineral resources, as well as normal colleges and universities; these schools have trained a large number of students and personnel with high and intermediate-levels of technical expertise for the country and the army, and this education has satisfied the needs of all kinds of talent for the national economy and national defense construction. Among them, there many people in governments and senior army cadres, as well as memberships in the CAS, the Chinese Academy of Engineering and the International Academy for Europe and Asia (IAEA); they are young academic leaders and the backbone of science and technology. These colleges and universities are also the scientific research base of cartography and geographic information engineering. A number of key national and provincial laboratories and engineering research centers have been built. A large number of research projects have been undertaken and completed, and the results have been applied in the construction of the national economy and national defense, especially projects under the financial aid of the National Natural Science Foundation of China, the National High-tech Research and Development Projects (863), and the National Science-Technology Support Plan Projects. A series of independent innovation successes have been achieved, and students have won the National Awards of Natural Sciences and National or Provincial S&T Progress Award. These projects have played a leading role in the development of these subjects in China.

1.4 Problems and Prospects

Since new China was founded 60 years ago, the field of cartography has developed from traditional cartography to digital cartography and is moving toward cartography informationization at the core of geospatial information services. Currently, cartography (map science) subjects have been developed into cartography (map science) and geographic information engineering (GISs) and have become national key disciplines, which is the most glorious stage in the history of cartography in China. However, with the rapid development of spatial information technology, communication and network technology, and spatial data processing technology, the development of cartography and geographic information engineering is facing many opportunities and challenges.

First, objectively speaking, the research of cartography and geographic information engineering science and technology in China was committed to the tracking, introduction and absorption of foreign advanced technology and less independent innovation. Undoubtedly, these methods have helped us to achieve progress in the science and technology of cartography and geographic information engineering in our country and catch up with the advanced level of developed countries. However, if we want to reach or even exceed the advanced level of developed countries, we must be committed to independent innovation, especially original innovation. Otherwise, it will be impossible to build the theory, technology and application service system for cartography informationization and realize a second leap in the development of cartography. Hence, it is necessary to greatly enhance the capacity of independent innovation in cartography and geographic information engineering. Independent innovation is the driving force for the whole evolution of cartography and geographic information engineering science and technology.

Second, information science is the foundation of today's social activities. Information acquisition, transmission, storage, processing and utilization technology are important parts of human activity. As the two technical backbones of information science, electronic computer and communication network technology has rapidly developed. The development goal of computers in the 21st century includes faster computing speeds, a higher degree of system integration, greater storage capacities, smaller sizes and multi-functions. The rapid development of communication network technology will change the way people work, live and interpersonally communicate. The traditional Internet realized the interconnection of computer hardware. The World Wide Web (Web) achieved communication in the form of a Web page. Currently, grid technology uses the high-speed Internet to link different geographically distributed resources, including computers, databases, storage and software, for full sharing of all information resources. The core idea is that the Internet is one computer. Considering such a situation, China's cartography and geographic information engineering disciplines may face many new problems. How do we deal with terabytes of space data with multiple users and quick and efficient information access? How can spatial data be transformed into spatial information and further into knowledge? How can the problems of information resource sharing and collaborative work in the grid environment be solved? How can we build a new generation of GISs, i.e., grid geographic information systems (Grid GIS), and provide diversified map services? And so on.

Third, the problem to solve using cartography and geographic information engineering science and technology is an information source. In the long developmental history of cartography, expeditions, field surveying, mapping and aerial photography were once used as means of map information acquisition, and these methods have promoted the development of cartography in different historical stages. Although remote sensing has become the main technical means of information acquisition from Earth observations since the 1960s, today, GIS spatial data mainly come from the digitalization of maps. The first reason is that image recognition technology lags behind; useful mass satellite image data have not yet been transferred into usable information. The second reason is that we cannot automatically extract vector data from images, as there is a lack of interaction between image data and vector data (Li 2004). The third reason is that the fusion of vector data and image data in GIS is far from perfect for the unreasonable administrative system of satellite images. Therefore, cartography and geographic information engineering disciplines should strive to research and solve the three aspects of this problem.

Additionally, the construction of digital society is the foundation of national modernization. Digital society is a broad concept, including digital Earth, digital countries, digital provinces (autonomous regions and municipalities) digital cities, digital rivers, digital oceans, and so on. All these digital concepts are currently in the process of construction. Among them, digital cities are the most representative or typical. A digital city brings together spatial information technologies (including GIS, remote sensing (RS) and global navigation satellite system (GNSS)) or computers, modern communication and network technology and information security technology to provide geographic information, information technology and information systems services for its enterprises, governments and citizens. Digital cities can visually reproduce the resource distribution situation of real cities by means of powerful system software and mathematical models on digitally integrated platforms consisting of urban, natural, social and economic factors. Digital cities can be used to analyze, simulate and research all kinds of schemes of planning, construction and management for real cities and to promote information sharing, communication and integration for users from different departments and at different levels. Digital city construction demands the full use of cartography and geographic information engineering science and technology, especially GIS technology. However, it should be said that the current gap is very large. The problems facing the cartography and geographic information engineering discipline during the new period are as follows. How can digital city information infrastructure be provided with spatial data and technical support? How can digital city application systems be provided with integrated GIS, MIS and OA software support? How can digital cities be constructed with geographic information sharing platforms? How can efficient geographic information services be provided for governments, enterprises and the public? And so on.

It is necessary to summarize the advances, problems and lack of advances in cartography in China since new China was founded 60 years ago and to analyze the development of spatial information science and technology and the discipline. With the arrival of the information age, the informatization of surveying and mapping has the characteristics of real-time global geospatial information acquisition, automated or intelligent spatial information processing, and popular spatial information services in a networked environment. Confronted with a new choice and challenge, the cartography and geographic information engineering discipline has much space for development (Wang 2008a, b).

1.4.1 The Innovative Subject System Will Be Improved and Perfected Based on Spatial Cognition with the Spatial Information Transmission Process as a System

The proposition that our discipline must be based on spatial cognition with the spatial information transmission process as a system reflects that service will be taken as the core idea in the information era. Spatial cognition is an important research field in cognitive science. Many studies on map spatial cognition have been conducted both at home and abroad. Spatial information transmission is a special research field that consists of information transmission. Many explorations on map information transmission modes have been performed both at home and abroad. Spatial information transmission models under digital environments have also been discussed.

By comparing the spatial cognitive system and geographical information system, we can discover a similar principle in the spatial information processing (handling) system. Spatial cognition is an epistemology; space information transmission is a methodology. The former runs through the entire course of the latter. Others, such as visual perception, geographic ontology, the map model and the spatial data scale theory, all belong to the applied theory used to correctly understand the geographic environment in the process of spatial information transmission. Many studies have been performed to date. Therefore, an innovative theoretical system of the discipline is likely to be constructed through further improvement and development by China's theoretical research workers in the cartography and geographic information engineering disciplines. The key is to move in the correct direction of research based on the overall discipline theory system, to plan research content in a scientific way and to improve the research methodology. Through independent innovation, we must build an integrated software system for digital mapping and publication with independent intellectual property rights based on the import, digestion and absorption of both hardware and software in digital cartography and publishing.

Integrating digital cartography with a publishing system (film output of color separation screening and digital plate-making) has been completed in China based on import, digestion and absorption of advanced foreign hardware and software. Although secondary software development and research works have been conducted according to the practical demand of mapping and publication, the whole system is subject to the limitations of MicroStation and its independent intellectual property rights. In recent years, we used this system to accomplish a great deal of mapping and production tasks. It is possible to further develop a set of microcomputer-based mapping software systems, including map design (general design, color design, symbol design and representation method design), map data processing (digital cartographic generalization, data processing of thematic mapping) and prepress editing and publishing (film output of color separation screening, digital plate-making). In fact, such small cartographic systems exist at present. It is important to make an overall design with reference to foreign hardware, to propose a solution of home-manufactured software and to develop a unified specification and interface. It is necessary to create a map design, map compilation (data processing), and prepress editing and publishing that are componentized and modularized products. Then, the general cartographic system and thematic cartographic system will be built.

1.4.2 The Intelligent Process Control and Quality Evaluation of Spatial Data Automatic Generalization Will Enter Its Application Stage

Intelligent generalization of spatial data is the most challenging and creative research area in the cartography and geographic information engineering disciplines. A large number of research results with great theoretical and technical value have been obtained by scholars in academic circles both abroad and domestically. However, due to the complexity of spatial data automatic generalization, the present research results do not apply to actual cartographic production and application, and many problems need to be solved. The purpose of process control and quality evaluation of spatial data automatic generalization is to ensure the quality of spatial data generalization. The focus of future research will be as follows (Wang 2008a, b). Innovation of ideological concepts will contribute to the innovative research and production applications of spatial data automatic generalization, and the research history in this area is proof that this is an effective method. The process of realizing spatial data automatic generalization has gone from simple to complex, from local to global and from digital to intelligent, and this process is far from being complete. Models and algorithms of spatial data automatic generalization must be continually improved and optimized with the advances in people's cognition and the development of science and technology. One major aspect of future research is to improve the intelligence level of automatic generalization. Knowledge engineering of cartographic generalization should be considered an important task. Objectively speaking, there are necessary bases for the engineering and industrialization of automatic generalization processes and quality control systems. Therefore, we should work with map production units to build engineering and industrialization bases. Once we have done these things, we will be able to develop an intelligent spatial data automatic generalization system (as a part of the whole digital cartographic system) with independent intellectual property rights. By that time, the following four problems can be solved. One problem is the use of large-scale digital map data for the production of smaller-scale maps. The second is the automatic derivation of a smaller-scale database from a large-scale basic spatial database and the all-in-one update of multiscale spatial databases. The third problem is to adapt to the needs of visualization and presentation of multiscale spatial data in GIS. The fourth is to extract user-required spatial data from distributed heterogeneous databases to build a spatial data warehouse.

1.4.3 The Virtual Geographic Environment Will Be Combined or Integrated with a Geographic Information System

GIS involves the expansion and extension of cartographic functions, while VGE is a new point in cartography. Each of them developed quickly, and the combination or integration of the two would be a solid foundation. In view of the interactive relationship between GIS and VGE, GIS has powerful capabilities for storage, management, processing and analysis of mass spatial data, while VGE provides the multidimensional and dynamic visualization of spatial information and the function of real-time interactive manipulation. Thus, the combination and integration of the two methods is an inevitable trend that helps to integrate the advantages of each other. As early approximately 10 years ago, the problem of integrating GIS with VGE was put forward (Su and Sheng 1997). The DVGE system framework constructed by using the HLA can be applied to the integrated management of multi-dimensional geographic information and multimedia integration, innovative scientific research, distributed collaborative planning, and design and decision-making (Xu et al. 2005). However, to realize the combination and integration of GIS and VGE, we must further develop a framework and a platform for the integration of GIS and VGE; research the web service registration, discovery and composition technologies under a network/grid environment; exploit an adaptive symbol system for the visual presentations of multiscale spatial data; and explore technical problems, such as the spatial-temporal modeling and simulation oriented evolution model. Only in this way will the function of the integration of GIS and VGE be more powerful, and the comprehensive utilization efficiency will be higher.

1.4.4 The Research Focus of Spatial Data Mining and Knowledge Discovery Will Convert from Theory to Application and Lead to the Emergence of a New Knowledge Map-a New Type of Spatial Data Processing Product

SDMKD expand and deepen spatial analysis and belong to one of the spatial data processing processes. To date, there has already been much research and many achievements. There have been some preliminary spatial data mining function modules specializing in processing spatial data both at home and abroad, such as GeoMiner, a spatial data mining prototype system based on the MapInfo platform being developed by Simon Fraser University in Canada, and the integrated human-computer interaction spatial-temporal data mining system developed by Wuhan University of China.

Overall, however, the research achievements in this field at home and abroad involve more scientific theory than practical application. Many scales of spatial databases, digital orthographic image databases, digital elevation model databases, and various professional (thematic) databases have been built in China. There will be many good opportunities for development and application of SDMKD. The existing data services may not be enough to satisfy the demands of users, especially policy-makers. There is a pressing need to obtain the knowledge hidden in data. SDMKD is actually an inevitable trend in spatial information technology development and social demand. The aim of data mining is to identify interesting and understandable knowledge and to further generate a visual knowledge map. As a kind of spatial data processing product, it is crucial to solve the imminent bottleneck of excessive data while knowledge is scarce. Next, we need to focus on the following aspects. Further study the SDMKD model and algorithm and develop many specific tool boxes for advanced knowledge discovery; explore spatial data and their complex relationships, such as the strong spatial-temporal correlation among spatial data, the information correlation relationship across different spatial and temporal scales, different organization hierarchies and different technology domains; obtain association knowledge, distribution pattern and spatial correlation; and research the visualization methods of knowledge and the automatic generation of all kinds of knowledge maps. These aspects will help to promote the practical application of SDMKD.

1.4.5 The Research Focus of Spatial Data Uncertainty and Spatial Analysis Will Shift to the Spatial Data Quality Evaluation and Control System

Because of the complexity and fuzziness of the real world and the limitations of human cognition and expression ability, spatial data and spatial analysis will inevitably present some uncertainties. Research on uncertainty theory in the processes of spatial data collection, processing, analysis and application is directly relevant to quality control in the processes of spatial data production, analysis and application. The spatial data uncertainty problem is a problem of spatial data quality. It is directly related to the reliability of digital map products and applications and the reliability of GIS spatial analysis. At present, systematic theoretical results have been obtained in the field, but they do not form any spatial data quality evaluation and control system and cannot be effectively used in the whole process of spatial data production and application. The uncertainty of the spatial data and spatial analysis results from the production and application of spatial data, and uncertainty theory is bound to return to the spatial data production and application process. To effectively guarantee the reliability of the production quality and application of spatial data, future research must focus on the spatial data quality content (elements) and evaluation index system in the whole process of spatial data production and application, the spatial data quality evaluation and control model, the data quality standards for the whole process of spatial data production and application, and construction of a spatial data quality evaluation and control system.

1.4.6 Web Services and Grid Services Will Become the Mainstream Mode of Current and Future Geographic Information Services

Along with the development of computer and network communication technology, GIS architecture has gone through several stages during the development process, i.e., host-based GIS, desktop GIS, WebGIS, distributed GIS and open GIS, while the development mode of GIS software has undergone a series of changes from the GIS function package, integrated GIS, and modular GIS to component GIS. There are some problems in the current WebGIS, such as the relatively fixed configuration of data and functions, relatively simple processing functions, and lack of interoperability among systems. In reality, cross-platform interoperability, resource sharing and collaborative work have not yet be achieved. On the one hand, driven by the ideas and technologies of open GIS, DGIS and component GIS (ComGIS), geospatial information sharing and spatial data interoperability, which are based on the web service standard of the SOAP, WSDL and unified description and integration (UDDI) and other standards, will become the mainstream mode of geographic spatial information services in both the present and future. On the other hand, the emergence and application of grid technology creates conditions in the broad sense of realization of resource sharing and collaborative problem-solving (work). There will be a super network consisting of a sensor network, working platform network and grid by adding a data service, functions service, calculation service, storage and resources services and a sensor service to the registry. Then, there will be a true sense of real-time dynamic GIS. Under the environment of GridService, the functions and data of GIS will be distributed; a one-stop service platform with data access and integration (DAI) services responding to user requests and service migration and service composition will become a mainstream service mode. The user will be able to enjoy the data service without the need for any data. Users can enjoy all GIS functions without any need to possess or install tightly coupled GIS software and services. Additionally, GIS software development models based on components will become mainstream. The core of both WebService and GridService is service. There are both similarities and differences between these services types. WebService is a stateless service, while GridService is a stateful service. Now, both services tend to merge with each other. They are the current and future main technology to realize networked/grid-enabled, popular and universal applications of spatial information services.

We review the progress in order to summarize achievements, find problems and consider the future to solve problems and promote development. Therefore, we can attempt to summarize the past and shape the future with scientific attitudes.

To put the vision of this subject into practice, we must firmly grasp the important weapon of ideological liberation, invigorate academic ideas, create a favorable academic atmosphere, and dare to be different when facing these academic issues. Additionally, we must seize the fundamental principle of independent creativity to innovate the theoretical system, technology system and service system of this discipline. Moreover, we must attach great importance to talent cultivation and innovation platform construction, especially leading technological talent and high-level open laboratories, freeing them to exploit their talent. As long as follow and implement the “scientific development” prompted by President Hu Jintao, over another 10 to 15 years, we will be able to solve the existing problems based on today’s achievements, and our vision of the future can become a reality. By then, cartography and geographic information engineering disciplines may realize the second leap forward in development.

1.5 Representative Publications

(1) ***Cartographic Reference Manual*** (Lu Quan, Yu Cang. Surveying and Mapping Press, July 1988)

The book consists of eleven chapters. Chapter 1 includes several new arguments on modern cartographic theory, such as cartographic theory structure, views about maps as spatial information carriers, and academic viewpoints related to basic cartographic theory, including map transmission theory, symbolism and information-pattern-epistemology. Chapter 2 introduces a newly developed classification method based on the traditional map classification method, including introduction of the map classification system in the *Thesaurus of Surveying and Mapping Science and Technology* according to the needs of automatic computer retrieval. Chapters 3 and 4 briefly discuss the history of cartography in China, provides readers with an understanding of the country's historical legacy of mapping, and discusses adaptations to the international new trend of studying ancient maps and the history of maps. In particular, the fourth chapter introduces the mapping situation during the period from the late Qing Dynasty to the Republic of China and the thematic mapping in China in recent years. Chapters 5 and 6 systematically summarize and introduce cartography-related international organizations and their activities and relevant publications both at home and abroad. These chapters conveniently enable readers to obtain clues to further explore the international advanced level. Chapter 7 mainly introduces the use of electronic calculators in map projection calculations. Chapter 8 covers significant ground with discussions of thematic maps, including navigation and aeronautical charts, and shows the further development trend from map compilation to thematic mapping. Additionally, Chapter 8 also reflects the tendency that since topographic map compilation involves precision measurements and error and the application of mathematical statistics methods, the theory of topographic map compilation is transitioning from qualitative to quantitative descriptions. Chapters 9, 10 and 11 systematically generalize and summarize all kinds of technologies and management methods in classical mapping, and these chapters introduce all aspects of new types of maps and mapping technologies.

(2) ***Introduction to Maps*** (Yin Gongbai, Wang Jiayao, Tian Desen, Huang Caizhi. Surveying and Mapping Press, December 1990)

The book systematically and comprehensively expounds all kinds of knowledge related to maps and introduces the development trend of maps, new concepts of modern cartography and new theories and technologies. This book is divided into 10 chapters. This chapter covers maps and cartography, introducing the definition of a map and its basic characteristics, the content, classification and function of the map, and the concept of cartography and its connection with other subjects is expounded. Chapter 2 is the mathematical basis of the map, and this chapter introduces the basic concept of map projections from the shape and size of the Earth, coordinate systems and elevations and its control points, describes the projection method and applications of Gauss-Krüge projection and conformal conic projection, and discusses the problems of map orientation, map scale, map subdivision and sheet numbering system. Chapter 3 covers map language and includes three main sections, i.e., map symbol, map color and map annotation. Chapter 4 discusses the general map and introduces the types and contents of general maps and describes the representation methods of natural geographical features, social and economic features and external margin elements. Chapter 5 presents the thematic map and introduces the characteristics, types and contents of the thematic map, as well as the representation of thematic map elements, such as point, line and shape, and comparisons are made among the various representations. Chapter 6 comprises the atlas and series map and information about atlases and series maps, respectively, are introduced, including definitions, classification, characteristics, captions and the geographical names index. Chapter 7 covers the map compilation and printing methods and mainly discusses the four aspects of the map compilation method, commuter-aided mapping, RS mapping and map printing. Chapter 8 discusses the main map works, with introductions of the main map products of China and foreign countries. Chapter 9 covers map analyses and applications, where map analyses are reduced to four methods, including visual analysis, map diagram analysis, mathematical statistics analysis, and mathematical model analysis; additionally, the applications of maps in the aspects of scientific research, national economy and national defense construction are emphatically introduced. Chapter 10 discusses the history of cartography, and based on the map origin aspect, the development course of cartography in ancient, modern and contemporary China is explored; further, the development track of ancient and modern cartography abroad is introduced, and the main tasks and goals of cartography in China over the next period are put forward.

(3) ***Map Application Study*** (Huang Wanhua, Guo Zhengxiao, Zhao Yongjiang, Li Linghui. Xi-an Map Press, November 1999)

The book is a total of 12 chapters. This chapter comprises the introduction, which mainly presents the architecture, research objects and research contents of map application studies and analyzes the existing problems and main tasks in the field of map application studies. Chapter 2 covers the formation and development of a map application study, and in this chapter, the three development stages of map application studies are mainly introduced, providing a brief history of map application studies abroad and the research work and contributions by both domestic and foreign scholars. Chapter 3 discusses the map function theory, including the basic characteristics, functions, roles and main usages of the map and the means and measures to improve the efficient use of the map. Chapter 4 covers visual map recognition and reading, including an introduction to the expression methods and representation methods of map language and map content; then, the recognition of map projections, cartographic generalization, map recognition and reading, the principle, routine and content of visual map recognition and reading, etc., are discussed. Chapter 5 discusses the map quality evaluation and mainly includes the factors and contents, standard and routine methods of map quality evaluations and the preparation of evaluation reports. Chapter 6 comprises map measurement and calculation and mainly discusses the determination of the ground point's position and elevation according to the topographic map, as well as the methods of distance measurement, area measuring and calculation and the Earth's surface calculation, ground slope measurement and volume calculation. Chapter 7 covers the map content analysis method, which mainly includes the diagram method, diagram analytic method, mathematical analysis, mathematical statistics analysis and information theory analysis. Chapter 8 presents digital mapping technology and application, including the digital map overlap analysis, map information description and presentation. Chapter 9 discusses geographical information systems - expansion and extension of map function, which generally includes introduction of the concept, function and application of GISs. Chapter 10 covers cartographic methodology, which includes the content and function of cartographic methodology, such as the method of using a single map, the method of using a variety of maps, the combined use of the map method and RS method, and this chapter presents some practical applications of cartographic methodology. Chapter 11 comprises the accuracy and reliability of map use and research, including an analysis of the factors that affect accuracy, the calculation of map accuracy and its influencing factors, the calculation of technical accuracy and its influencing factors, cartographic generalization and its impact on the accuracy and reliability of map study, and so on. Chapter 12 includes an investigation of map users and utilization efficiency, in which the content, manner and means of surveying, as well as the organization, implementation, and writing of the report are introduced, and the present situation of foreign map users and relevant surveys are described.

(4) ***Cartography*** (Zhu Guorui. Wuhan University press, January 2004)

The book is composed of 17 chapters that are divided into six parts: map and cartography, map projection, map data and map symbol, design of map graphics, color and annotation, map design and map compilation, map publishing and printing, as well as its analysis and application. Chapter 1 and 2 introduce basic knowledge of the map and mapping process and the basic concept and development of the cartography trend, respectively. Chapters 3, 4 and 5 introduce the basic theory of map projection, several commonly used map projections, such as conic projection, azimuthal projection, cylindrical projection, pseudoconical projection, pseudocylindrical projection, pseudoazimuthal and polyconic projection, and the application and transformation of map projections, respectively. Chapters 6, 7 and 8 introduce map data, map symbols and the representation method of map content, respectively. Chapters 9, 10 and 11 introduce map graphics design, map color design and map annotation design, respectively. Chapters 12, 13, 14 and 15 present cartographic generalization and cartographic mathematical models, including regression models, square root models, hierarchical models and classification models, map editing and compilation and atlas compilation. Chapters 16 and 17 introduce the electronic map and electronic publishing of the map and map analyses and applications, respectively.

(5) ***The Principle of Cartography*** (included in Chinese college and university teaching material for the 21st century) (Ma Yaofeng, Hu Wenliang, Zhang Anding, Chen Fengzhen. Science Press of China, June 2004)

The book completely and systematically introduces the essence of the map, including the theory, technology and method of map-making and map use. This book contains nine chapters. The first chapter is an introduction, which mainly presents the basic concept of maps and cartography and synoptically introduces the methods of map-making, a brief history and the cartographic progress. The second chapter introduces the mathematical foundation of the map, with brief introductions of the Earth ellipsoid, geodetic control, map scale, map projection and its basic principle, several kinds of commonly used map projections, map projection discrimination and choice and the automatic generation and transformation of map projections. The third chapter covers map language, which mainly discusses the characteristics, classification, quantified expression and visual variables of map symbols, as well as the effects of visual perception, map symbol design, map color and design, and map annotation. The fourth chapter covers map generalization, with brief introductions of the map generalization essence, the influential factors of map generalization and the principles and fundamentals of map generalization; simultaneously, automatic map generalization is also roughly introduced. The fifth chapter presents a general map, with introductions of the basic concept of a general map, the representation methods of natural geographical features and socioeconomic features, map orientation and topographic map query, and includes a description of the present situation of the national fundamental geographic information database. The sixth chapter discusses the thematic map, which mainly includes introductions of the thematic map basic concept, the characteristics of thematic elements and its presentation methods, and a briefly introduction to the characteristics and types of atlases and electronic atlases. The seventh chapter covers map design and production, including the general process of map compilation, the design of general maps and thematic maps, and new technologies involved in map plate-making, printing and map production. The eighth chapter discusses modern mapping technology, which mainly includes introductions to the hardware and software of computer-aided mapping and databases, map editing and production, RS mapping, GISs mapping, electronic map systems, and so on. The ninth chapter is composed of map analyses and applications and mainly introduces the basic concept, technologies and methods of map analysis, as well as several kinds of geographical element analysis methods, topographic map reading and field applications.

(6) ***Principles and Methods of Cartography*** (national finely designed course materials of China) (Wang Jiayao, Sun Qun, Wang Guangxia, Jiang Nan, lv Xiaohua. Science Press of China, the first edition was printed in March 2006, and the second printing occurred in July 2007)

The book systematically and completely introduces the principles and methods of cartography. There are a total of 18 chapters divided into six sections: introduction, mathematical foundation of map, representations of map contents and elements, cartographic generalization of map contents, technologies and methods of modern cartography and map analyses and applications. This chapter and Chap. 2 introduce the map and cartography, respectively. Chapters 3, 4 and 5 discuss the basic principles of map projection, commonly used map projections, map mathematical foundation design and map projection transformation. Chapters 6, 7 and 8, 9, 10 through 11 introduce information sources and their processing, as wel as map symbol designs, designs of the map overall effect, content representation of the general map, content representation of the thematic map, and the characteristics of special maps and the representation method. Chapters 12 and 13 discuss the basic theory of cartographic generalization and cartographic generalization methods for all kinds of map content elements, respectively. Chapters 14, 15, through 16 introduce digital mapping and map databases, digital mapping technology, and other new mapping technologies, such as multimedia electronic maps and Internet maps. Chapters 17 and 18 discuss map analyses and map applications, respectively.

(7) ***A New Cartography Course*** (a Nationally Planned Textbook of Regular Higher Education for "the 11th Five-year National Plan") (Mao Zanyou, Zhu Liang, Zhou Zhanao, Han Xuepei. Higher Education Press, April 2008)

The book is the basic teaching material for the geography field. The first edition was published in 2000; this book is the second edition. The book is divided into 10 chapters and covers the basic problems of cartography. Among these chapters, the first chapter is an introduction to the definition and characteristics of a map, the function of the map and its classification, the history of the map and the current development, the mapping method, and definitions of cartography and related disciplines. The second chapter covers geoids and map projections, with a focus on geoids, geodetic systems, map projections and map scale. The third chapter discusses map data, which involves terrestrial observation data, multisource RS data and global positioning system (GPS) data, as well as map data processing and map databases. The fourth chapter covers cartographic generalization, which outlines the nature, influencing factors, content and methods of cartographic generalization and its current development, and compares manual and automatic generalization. The fifth chapter presents map symbolization, which includes the map symbol (map language), map symbol classification and quantified expression, visual variables and colors of map symbols, the mental perception of symbols and graphics, and map annotations. The sixth chapter is map representation, which discusses the representations of geographical data that appear in point, linear or polygon distributions, the expressions of 3D spatial information and contour lines, and the dynamic representation of geographic information. The seventh chapter presents map editing, where first, general maps and thematic maps are introduced, and then, thematic map editing and design, atlas editing and RS photomaps are introduced. The eighth chapter covers digital mapping, which mainly includes introductions of the theory and technique of digital cartography, the digital mapping method and GIS-based digital mapping. The ninth chapter comprises map reproduction, which mainly includes the traditional lithography process, electronic publishing and prepress system, the development of modern map reproduction methods and the publishing management of map production. The tenth chapter includes map analysis, which separately introduces the mathematical methods of map analysis, reading analysis, graphical analysis, composite analysis and map information about Tupu (a geoinformatics graphic analysis).

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