National Report of China to ICC 2023

The Progress and Trend of Cartography and Geographic Information Engineering in China (2019-2023)

CHINESE SOCIETY FOR GEODESY,

PHOTOGRAMMETRY AND CARTOGRAPHY

June, 2023

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Photogrammetry and Cartography**

Abstract: Based on the development of cartography and geographic information technology in China since 2019, this report summarizes the achievements in theories of cartography, digital cartography and press techniques, updating of China's National Fundamental Geographic Information Database, geographic information technology and industrial development, geographic information applications and services, atlas compiling and publishing, and the new online map. Finally, the report offers some prospects for the developing trend of cartography and geographic information engineering in China.

Keywords: cartography and GIS, national report, achievement, developing trend

1. Introduction

With the rapid development of artificial intelligence, big data and mobile communication technology, the advancement of cartography and geographic information technology has also been accelerated and geographic information services have been extended to the national economy and people's lives. Cartography and geographic information technology become more and more closely related to social development, which has achieved rapid development and encouraging results.

2. The progress of cartography and geographic information engineering in China

2.1 New advances in theoretical research on cartography and geomatics

Cartographic theory has remained the focus of the academia and industry of cartography in China. Recently Chinese scholars have made in-depth studies on Pan-map, cartographic generalization and spatio-temporal data models, and have made a series of new achievements.

To meet the needs for developing the discipline of cartography in the digital economy era, digital map has gradually evolved into a mainstream area of competition and growth in the field of digital media. It continues to expand in terms of the objects, means, and forms of expression, giving rise to new media maps such as spatio-temporal big data map, cyber map, metaphor map, cartogram map, and micro-map. The expression paradigm of classical maps has been extended and expanded, forming the “Pan-map” theory. This theory unifies the traditional standard maps with various innovative forms of map-like representations and provides a new path for discussing the theoretical development of map studies in the era of information and communication technologies[1]. With the widespread application of maps in scientific research, social services, and public life, the content conveyed by maps has shifted from thematic geographic information organized by layers and topics to various ubiquitous information. There has been a tremendous change in cartographic subjects, expression objects, display media, and presentation techniques. The contents, methods, and styles of map expression are all heading towards diversity, and a large number of non-traditional maps have emerged that differ from traditional maps in terms of objectivity and accuracy, such as distorted maps, subway maps, augmented reality maps, metaphoric maps, etc., which are collectively referred to as "Pan-maps". Pan-maps, as an extension and expansion of existing maps, have comprehensively expressed the three-dimensional space including geographic space, human and social space, and information space[2-3].

In the field of cartographic generalization, the focus of theoretical research lies in the intelligent process control and quality evaluation based on comprehensive elements and processes that are controllable. Computer-aided automated cartographic generalization is essentially a highly intelligent system, where cartographic generalization knowledge plays a crucial role. Such knowledge can be classified into five categories, namely the descriptive knowledge of geographical characteristics of the spatial features, the knowledge rules for operation item selection, the knowledge rules for algorithm selection, the cartographic generalization for specific geographic features, and the knowledge rules for regional cartographic generalization. By fully utilizing all models, operators, algorithms and knowledge, etc., a scientific and systematic operation process can be formed, and by implementing intelligent control of the process, the automated generalization system can make a qualitative leap forward in its capability, which is called automated cartographic generalization process-control. With the formation of the big data scientific paradigm, spatial data generalization not only focuses on graphic generalization, but also needs to be combined with data learning and knowledge discovery. Through a large number of case studies in cartographic generalization, machine learning activity and data-driven subjectivity can be leveraged to enable intelligent technologies such as deep learning and knowledge graphs to find new applications in cartographic generalization[4].

With the advent of the era of informatization and spatial big data, new demands for the expressing and analysing ability of cartography have been created. Chinese scholars have proposed the concept of geographic scenario. A six-element representation model of geographic information has been proposed, including “spatial locations”, “geometric forms”, “characteristics of attributes”, “relationship between elements”, “evolutionary process”, and “semantic description”. A unified GIS data model integrating the six elements based on geometric algebra, a new GIS data structure driven by geographical rules and interaction, and unstructured spatio-temporal data organization and storage have been designed, injecting new research content and expression methods into the development of cartography[5].

2.2 The wide application of digital cartography and publishing technology

For digital cartography, China has adopted the advanced database-driven cartographic technology and method, and has integrated geographic information updating with map symbolic publishing. Dynamic updates, incremental updates, cascading updates, and element updates of the multi-scale map database and the entity-based data model have been implemented. By establishing a series of cartographic representation rules, the cartographic production system for topographic maps driven by spatial database has realized the automatic optimization and configuration of cartographic element symbols, annotations and marginal representation, and can flexibly carry out cartographic editing and processing of graphic relations, having greatly improved the efficiency of cartography. By 2022, a 1:50000 map-database has been built with integrated storage and management of the cartographic database and topographic database for 12 consecutive editions per year, and cascade updating of topographic and cartographic data has been realized, with a nationwide topographic map at scale of 1:50000 being printed and published. On the basis of updating 1:250000 and 1:1000000 scale topographic database, the corresponding cartographic database is updated synchronously. By using the updated cartographic database, one can quickly print out the latest version of the standard topographic maps or customized maps as required.

Nowadays, the fusion of multi-source geospatial vector data is one of the main tasks for studying digital cartography. Data fusion technology of the multi-source geospatial vector data is an important way of and valid method for solving the problem of inconsistency between geometric positions and characteristics of attributes of the multi-source geographic data. By spatial datum transformation, data format conversion and the attribute encoding correspondence etc., the point positions, graphic shapes and contents with varying degrees of detail for geographic information data have been preliminarily unified and integrated. Then geometries and attributes of spatial data are matched, and information about geometric shapes and attributes is updated to integrate and consistently process geometric information, attributes and spatial relationships, which facilitates the availability of more reasonable, up-to-date, more rational, reliable and useful geospatial data[1]. With the emergence of volunteered geographic information, vehicle spatial-temporal trajectory contains rich geometric and semantic information of the roads, which has become an important way to obtain roads data and traffic status. Furthermore, the cascading updating method for multi-scale spatial data based on the multi-scale entity matching is established. It first detects and extracts the updated information, then transmits the updated information between the scales according to the entity relation information combined with geographic generalization knowledge. To ensure consistent expression for multi-scale entities with the same name, the spatial conflicts are detected and resolved in the end[7].

2.3 Continuous updating of China's National Fundamental Geographic Information Database

With 30 years of development, the construction of China's National Fundamental Geographic Information Database has gone through the development process of initial database construction, comprehensive updating and dynamic updating. The construction and updating mode of multi-scale geographic information database has made a systematic breakthrough. A complete technical chain for quantitative calculation of spatial relations, identification of spatial distribution characteristics, cartographic generalization process control, and cascade updating and quality evaluation of results have been formed. The department responsible for surveying and mapping in China has launched the project of dynamically updating China's National Fundamental Geographic Information Database since 2012. The key and associated elements of the 1:50000 National Fundamental Geographic Database are updated and published annually. Then the updated 1:50000 database will be used for updating the 1:250000 and 1:1000000 databases. The total elements of the 1:50000 topographic database include such 9 major categories as transportation, residential areas, boundaries, geographical names, pipelines, water, soil and vegetation, terrain features and control points, and geographic features of more than 470 minor categories. The key elements refer to the 6 major categories which change frequently and have a great impact on economic and social development, including transportation, residential areas, boundaries, geographical names, pipelines, and water with 117 minor categories of elements. The associated elements include 2 major categories—terrain features and soil and vegetation with 57 minor categories. Since 2014, total element renewal has been carried out at the same time. About 50% of the key-element and total-element areas will be updated each year, so that the key elements can be updated once a year and the total elements can be thoroughly updated every two years. After the annual update, China's latest version of the 1:50000 topographic database will be built in time to keep it up-to-date with a delay of no more than one year and realize the management and service of multi-temporal data to comprehensively improve the data results in terms of time-effectiveness, practicability, accuracy, and application value. By the end of 2022, the 1:50000 database has been dynamically updated for 12 rounds.

Since 2014, the incremental data results created by dynamic updating of 1:50000 database have been used annually for cascade updating the 1:250000 database so that it is consistently up-to-date with the 1:50000 database. After several rounds of updating, the elements and attributes of the 1:250000 topographic database have been enriched. The dataset has been increased from 9 to 32. Minor categories of elements have been increased from 158 to 229. The data structure is more optimized and reasonable, which enables coordination and correlation with the 1:50,000 database, comprehensively and continuously improving its current status. Since 2016, the latest 1:250000 topographic database has been used annually to update the 1:1000000 topographic database to make it consistently up-to-date with the 1:250000 topographic database.

In terms of integrating and upgrading the 1:10,000 database, all provinces, districts, and cities have constructed databases on the basis of integrated data in accordance with requirements of the national database construction scheme or specifications. Then the 1:10000 database management and service system has been optimized and upgraded. The 1:10000 database has been fully integrated and upgraded. Meanwhile, provinces and municipalities were organized to further carry out dynamic update for the provincial 1:10000 database and cascading update with the national 1:50000 database.

Completion of the above work lays a solid geospatial data foundation for constructing China's digital earth, digital country, digital province, digital city, digital river and digital ocean, and provides timely and reliable geospatial data support for the national and regional economic planning, disaster prevention and mitigation, farmland water conservancy construction, post-disaster reconstruction, major engineering design and construction, and national defense construction.

2.4 Rapid development of geographic information technology and industry

In the field of Geographic Information System (GIS) technology, significant breakthroughs have been made in key technologies for autonomous and controllable high-performance GIS, and the technical problems such as spatial data management, parallel computing and intelligent analysis, automated processing and high-performance services that brought by the transition of GIS architecture from serial to parallel have been solved. Traditional GIS in terms of time, space, attributes, relationships, behavior, and cognition has been extended and upgraded by the technology of the Pan-space information system, and the multi-grained spatio-temporal objects were used to describe the real world from micro to macro scales. New progress has been made in network sharing and simulation technology of geographic analysis model, and unified expression of geospatial analysis models, resource sharing through service-oriented architecture, and simulation and analysing of model integration have been realized. This provides powerful support for spatio-temporal AI scenario analysis of urban areas, construction of city information modeling (CIM), and geospatial information disaster modeling in multi-hazard coupling scenarios. Additionally, a global location information superposition protocol and location-based service network technology system have been established. Geographic IP has been built by integrating unified spatio-temporal coding and location embedding. Spatio-temporal accuracy, ubiquitous location semantic perception capability, and intelligent services based on location overlay and fusion has been enhanced by the connection with three networks (Internet, Internet of Things (IoT), sensor network). The fusion and analysis system for Internet geospatial information has been established, and research breakthroughs such as geospatial information discovery and acquisition from deep web, ubiquitous geospatial information cleaning and feature-level aggregation, and content analysis have been achieved. Dynamic updating of geospatial elements such as roads, residential areas, and buildings has been effectively resolved by using the ubiquitous network information.

In the research and development of geographic information system, large numbers of GIS software are emerging. By 2021, China has had more than 1000 enterprises engaged in GIS software and application development, including software, hardware, training and education. Domestic GIS software continues to expand the market share, which has occupied most of the market now, with the output value of billions of dollars, widely used in urban planning and management and other fields. They have produced such excellent software as SuperMap of SuperMap Software Co., Ltd., MapGIS of ZONDY CYBER GROUP Co., Ltd., GEOWAY of GEOWAY Times Software Co., Ltd. and GeoStar of Wuda Geoinformatics Co., Ltd., some of which has successfully entered Japan, South Korea, India, Italy and other countries and regions, initiating the internationalization of GIS software in China. The technical level of domestic GIS platform software has been equivalent to that of foreign similar software, realizing the comprehensive localization of a new generation of geographic information platform software based on CPU, operating system and database. Chinese Academy of Surveying and Mapping, along with other related institutions, has been carried out the construction of the national digital city/smart city spatio-temporal big data platform. Actively collaborate with the national new smart city construction evaluation work, they carried out innovative research and product development based on independent technology. The domestic NewMap platform software has been developed, overcoming a series of key issues such as the open architecture with loose-coupling model, Pan-space integrated modeling, and scalable place name and address encoding. The related technologies have supported the construction of digital city spatial frameworks for 334 prefecture-level cities and over 600 county-level cities nationwide, as well as over 60 smart city spatio-temporal big data platforms. Among them, 40 smart city spatio-temporal big data platforms have been completed, providing real-time, comprehensive, and authoritative spatio-temporal infrastructure support for natural resource monitoring and management, smart city construction, economic development, and public life.

China's geographic information industry has been developing from scratch for 30 years since the reform and opening up. The focus of industrial development has extended from the initial emphasis on software development and data processing to service and application. In recent years, the scale of China's geographic information industry continues to grow rapidly. In 2018, the annual output value of China's geographic information industry exceeded 595.7 billion yuan. By 2021, the annual output value of China's geographic information industry exceeded 752.4 billion yuan. The number of industrial units has been over 164000, among which more than 16000 enterprises have surveying and mapping qualifications. Many geo-information enterprises are listed at home and abroad with more than 3.98 million employees[8]. The rapid development of geographic information industry allows its industry chain to gradually improve, which enhances the overall scale and efficiency of the industry and improves the level of independent innovation. To promote and support the growth and development of geographical information industry, various districts are actively building geo-information industrial parks or industrial incubation bases. According to statistics, more than 60 geo-information industrial parks or industrial incubation bases are under construction or have been built in China, each of which having its own characteristics. Among them, the permanent meeting venue of the high-level forum on United Nations Global Geospatial Information Management (UN-GGIM) is located at the Geospatial Information Industrial Park in Deqing, Zhejiang Province.

In the future, with further deepening of the reform and opening up, the deep integration of surveying and mapping geographic information into natural resource management, the support of national industrial, scientific and technological innovation policies, and the continuous growth of global geographic information market, the development of China's geographic information industry will usher in a more brilliant tomorrow.

2.5 Diverse application of geographic information in various fields

In recent years, the application of geographic information in various fields such as government affairs, industry, scientific research, and public sectors has continuously expanded and strengthened. It has deeply integrated into all areas of the national economy and social development in an all-dimensional and multi-level manner. It has become a companion object in the entire life cycle of "smart" information system construction, and the "GIS+" application mode has been increasingly deepened in the "government-industry-university-research-application" ecosystem. As a significant carrier of geographic information, digital maps have evolved from "spatial background" or "browse window" to become the "solution" for industry big data visual analysis systems. Dynamic digital maps displayed on various electronic screens of different sizes have become the user interfaces and a "standard configuration" of diversified information system. Moreover, by integrating "computing +" methods such as new media information visualization, the organic fusion of the intuitiveness, comprehensibility, decorative design of maps and the dynamics, interactivity, and real-time nature of digital technology is achieved, forming a "map +" application model, which is dynamic, three-dimensional, flowing, interactive, and online.

The booming development of navigation electronic maps provides crowd-sourcing mapping, commercial analysis, and enterprise services for a wide range of users. More than 500 million users have used products and services such as vehicle-mounted navigation, mobile positioning and location query, and the products have covered all highways, national roads, and provincial roads, achieving uninterrupted guidance for all cities, counties, and villages nationwide. Navigation electronic maps and navigation technology have driven the development of automobile, tourism and other related industries. Domestic electronic map products, such as Baidu Map, AMAP, Tencent Map and Tianditu (or Map World), have launched some more professional navigation map products, combined with the location based service (LBS), artificial intelligence (AI), virtual reality (VR) and augmented reality (AR) technologies to promote the connotation of the navigation electronic map service. Among them, Baidu Map proposes to build an intelligent travel platform from artificial to automatic, plane to three-dimensional, static to real-time, and from fingertips to voice, providing AR walking navigation, intelligent recommendation of boarding point, personalized map and other intelligent services. AMAP has introduced new functions for AR real scene navigation and is working to create new applications that combine AR with LBS. Navigation electronic map industry has also widely penetrated into online food delivery, housing, ridesharing, social networks, online games and other fields, making people's various life needs greatly facilitated.

In recent years, with the construction of large commercial centers, airports, sports venues and museums, people's demand for mobile positioning and navigation electronic map services has been expanded from outdoor to indoor, thus promoting the application and development of indoor navigation electronic map. With the popularity and increasing functionality of smartphones, indoor mapping has been made possible through various indoor sensor technologies such as WiFi positioning, inertial navigation, Bluetooth, and RFID. These technologies have enabled the mapping of the relationship between people, locations, and businesses. The research mainly focuses on three aspects, including indoor map modeling, indoor map representation, and indoor map positioning and navigation application.

The rapid development of the intelligent networked industry has led to the resonance between automatic driving and the geographic information industry, and high-precision dynamic maps are in a period of rapid development. According to data, by the first half of 2022, there will be 2.28 million passenger vehicles in China equipped with combined driving assistance features, but there are still many challenges to the application of high-level automatic driving systems in complex urban scenarios. Creating a comprehensive and high-precision navigation map by integrating data from multiple sources, including collecting holographic road data, extracting static and dynamic road information, and merging dynamic and static data can enrich road information, improve road accuracy, and enhance map update efficiency[9]. The goal is to develop an industrial system centered around a high-precision dynamic map platform, providing industry users with more accurate, richer, fresher, and safer high-precision dynamic map data services, and support the rapid application and development of advanced autonomous driving systems in various scenarios, and promote efficient and high-quality collaboration and development across related industries.

2.6 The prosperity of atlas compilation and publication

In recent years, high-quality atlas products have constantly emerged in China, with the map market getting more prosperous. In terms of thematic maps and atlas, representative works include *Atlas of Administrative Divisions of the People's Republic of China*. It compiles new achievements in administrative division adjustments, place name census, and administrative boundary delineation. It comprehensively and systematically reflects the current legal administrative division information in China, providing services for national administrative management, economic development, social progress, and international communication. *Atlas of the First National Geographical and National Condition Census*, based on the data of China's first geographical census, is organized and analyzed through multiple sources of census data. Utilizing a scientific database mapping method, it visually demonstrates the spatial distribution characteristics of China's natural and human geographical elements and the spatial distribution relationship between geographical census thematic elements and China's natural landform features at multiple scales. This atlas fills the gap in the publication of professional thematic maps in geographical and national conditions. The *World Navigation Atlas* is China's first comprehensive atlas that fully reflects the world navigation knowledge. It consists of four chapters: World Scenery, Resource Environment, Navigation Support, and Key Navigation Areas. Combining maps, nautical charts, remote sensing images and other expression forms, the atlas vividly interprets the latest developments along the 21st Century Maritime Silk Road. *Atlas of Port and Shipping of Chinese North Hub Port* is the first regional port and shipping atlas in China that focuses on the port environment and navigation support of China’s northern sea area. It fills the gap in the domestic comprehensive port atlas. *Atlas of Chinese Water* is a large-scale comprehensive atlas concentrating on water. It consists of five parts: the preface, water bodies and hydrological cycles, heavy rain and floods and droughts, water resources, and water projects. It systematically describes the quantity and quality of various forms of water in China, the laws of water circulation and its spatial distribution, the current situation of development, utilization, and protection of water, and the relationship between water and social and economic development as well as environmental protection. The atlas summarizes the achievements and experiences of China in the practice of water management and control. *Atlas of Chinese Mountain Flood Disasters* shows the characteristics, content, and important achievements of China's mountain flood disaster-forming environment and its prevention and control efforts from multiple perspectives. It serves as an important reference for implementing the new era's flood and drought disaster prevention strategy and strengthening emergency management. The *Natural Disaster Risk Map Collection* combines the natural environment and socio-economic characteristics of the ‘Belt and Road’ region. It investigates the disaster-forming, disaster-caused, and disaster-bearing environmental changes of earthquakes, geology, droughts, floods, and oceans. By using multi-scale risk assessment methods, it achieves risk assessment of various types of disasters in the whole region, local areas, communities, and projects. *Atlas of Asian Groundwater and Environment* features six thematic sections: Asian hydrogeology, groundwater resources, geothermal resources, groundwater quality, geological environmental effects of groundwater development, and groundwater ecological environments. Through its specialized illustrations, the atlas establishes an organic relationship between human activities and the climate, geology, structure, landforms, hydrology, ecology, and environment of the Asian continent. This work serves as a valuable reference for research on Asian groundwater resources, geothermal energy, and environmental geology. Additionally, *Atlas of the 100th anniversary of Communist Party of China* presents the Communist Party's glorious journey of leading and uniting all Chinese people to strive for national independence, people’s liberation, and the realization of national prosperity and people’s wellbeing over the past century, from both a temporal and spatial perspective. *Chongqing: Weekly Map Atlas* is a city cultural atlas that tells the story of Chongqing from a geographical perspective using maps. *Atlas* of *Stroll in Luo Jia Map* and *Atlas* of *East China Normal University* are exemplary campus cultural map atlases. In addition, thematic map atlases and thematic maps such as the *Atlas of China Urban Agglomeration*, *Atlas of World Mountains Above 8,000 Meters*, *Atlas of Coastal Bays Land Use Changes in the South China Sea*, *Atlas of South Asia Resource and Environmental*, *Series Maps of Qinghai-Tibet Plateau Desert Ecosystem*, *Atlas of China's Surrounding Sea Submarine Terrain and Place Names*, and *Series Thematic Maps of China's Snow Characteristics* all show significant academic and cultural values.

In recent years, numerous high-quality works have been published in the comprehensive provincial and municipal atlas. The design of the atlas adheres to the philosophy of "tradition and innovation coexisting, historical heritage and modern development equally emphasized." And a great deal of innovative practice in content arrangement, visual expression, narrative style, and information dissemination has been carried out. Representative works include *Atlas of Anhui Province*, *Atlas of Hunan Province*, *Atlas of Jilin Province*, *Atlas of Guangdong Province*, *Atlas of Jiangsu Province*, *Atlas of Shanghai*, *Atlas of Shenzhen*, etc. The compilation and publication of these atlases not only provide important reference for government departments to understand the situation of the province and make scientific decisions but also offer abundant geographic information services to society. Furthermore, they also open a fascinating cultural window for readers.

The ancient maps constitute a precious cultural legacy of the Chinese nation and represent a significant medium for the inheritance of Chinese civilization. To promote the transformation, utilization, and dissemination of these valuable treasures, a series of excellent works on ancient maps have been published. Among these, the representative work is "*China's Modern Map Chronicles*", which collects more than 200 ancient maps from the Ming Dynasty to the Republic of China. These maps are classified and summarized into 11 themes, including world maps, astronomical maps, boundary and political maps, provincial and regional maps, topographic maps, maps of rivers, lakes, and water transportation, nautical charts, military maps, city maps, scenic maps, and educational maps. Each theme is explored in the form of "one map, one chronicle", which expounds the development characteristics of maps in different periods. *Collection of Historical Maps of Anhui Province: Ancient Maps Volume* contains 339 ancient maps from the Northern Song Dynasty to the founding of the People's Republic of China in 1949. These maps, accompanied by concise historical interpretations, utilize visual and symbolic language to comprehensively illustrate the historical development of Anhui Province, providing insights into the past and present of the Jianghuai region. Similarly, the *Compilation of Ancient Maps of Urban Changes in Northwest China* includes 268 typical and representative ancient maps of the region. This classic work interprets the historical changes of urban development in Northwest China through the language of ancient maps, and has significant historical reference value for promoting urbanization and scientifically formulating the strategic planning and urbanization development, especially in Northwest China.

On the basis of the second national geographic names census of China, a number of provincial, municipal, and autonomous region standard geographical name atlases have been compiled and published. Examples of these include the *Standard Geographical Name Atlas of Hubei Province*, the *Standard Geographical Name Atlas of Heilongjiang Province*, the *Standard Geographical Name Atlas of Guangxi Zhuang Autonomous Region*, and the *Geographical Name Atlas of Wuhan City*. These atlases collect administrative divisions, the second national geographical name census, administrative boundaries, and national basic geographic information, providing authoritative, systematic, and accurate information about administrative divisions and geographical names for society. They are of great significance for promoting economic development, strengthening geographical name management, and protecting and inheriting outstanding geographical name culture.

2.7 Flourishing of new types of online maps

Due to digitization, networking, mobilization, and ubiquitous development trends of map applications, new media maps integrate various multi-source spatio-temporal data to form a new model of online map services, including mashup maps, crowdsourcing maps, event maps, intelligent maps, holographic maps, and micro-maps. Meanwhile, combined with various sensors, the map-oriented multi-mode human-computer interaction mode was explored, including voice, handwriting, gesture, expression perception, etc., as well as the intellisense and service driven of position, orientation and speed. This creates a relationship model between map and users with universality, limited personalization, and high personalization.

Map mashups seamlessly join together the interactive functions and Internet map contents of government cartographic departments, private software developers and volunteers. Its open map services allow users to share updates from other users. Crowdsourcing map adopts the crowd-sourcing mode to build a map service with public participation. It can be either a way to provide map data or a way to make maps. It has been used in high-precision navigation data acquisition and update, indoor map data acquisition, and mapping services and so on. The combination of map mashups and crowdsourcing maps facilitates the swift transition of data and content production in map-making from professionally-generated content (PGC) to user-generated content (UGC). This has lowered the threshold for the development of next-generation online maps, ultimately enhancing the user experience and encouraging innovative applications.

Event map is to superimpose various events on the map targets, including time, place, changing mode, and information about people or things involved. It can organize events into visual stories in a logical way with a clear theme and purpose. Event map, with a stronger visual impact than static map, can more effectively arouse the reader's empathy and produce a kind of charisma that can change the reader's attitude or behavior. Intelligent map, combined with cloud computing, Internet of Things, mobile Internet, artificial intelligence and data mining technology, etc., by integrating the layer data with multi-source, multi-scale, multi-space-time and multi-structure elements, closely following the geographic information service requirements of whole-space, full-information, all-media, full-cycle and full-service, and emphasizing the dynamic integration between the human expert's knowledge and maps, forms a new dynamic mutual-promoting and mutual- decision-making-support map mode and adapts to the great impact brought by the professional spatio-temporal big data[10]. Location-based holographic map realizes the association of multi-dimensional spatio-temporal dynamic information through location, and effectively links various spatial information, sensor network information, social network information, volunteered geographic information, and real-time public service information, etc. It is a kind of map form of personal centered Pan-space information display and intelligent service[9].

To address the ever-emerging new demands, new types of online maps innovate the technical thinking of cartography, combined with diversified map themes, map knowledge in graphic form, template-based map refinement, dynamically customized thematic symbols, flexible map interface, customized map products, versatile map platforms, and comprehensive user coverage, integrate service-oriented architecture in a cloud computing environment. The framework uses new web visualization technologies and component models to innovate in multiple areas, such as cartographic knowledge database, full-cycle mapping scenario templates, and rapid dynamic mapping engines. These techniques help create a cross-media participatory mapping environment that offers personalized map services, including subscription-based, order-based, customized, and intelligent mapping service technologies. Cross-media platforms, including web browsers, web applications, and native apps, are used to facilitate this digital map service innovation.

3. The future development of cartography and geographic information engineering

3.1 Future tasks and development directions of cartography and geomatics

Since 2019, China's surveying and mapping geographic information industry has entered a new stage characterized by transformational development, vigorously promoting the development of new fundamental surveying and mapping, geographic information public services and industries. The technology system of GIS data rapid acquisition and updating has been constructed by applying technologies such as remote sensing, GNSS, LiDAR, and digital mapping. At the same time, various types of sensors and intelligent terminals with positioning functions are becoming more and more popular, promoting the construction of multi-source geospatial big data. On this basis, combined with modern information technologies such as big data, cloud computing, and artificial intelligence, the development of cartography from digitization to intelligence has been effectively promoted, thereby meeting the diversified needs of different users in society for dynamic and customized map expression and application. Therefore, according to the requirements of high-quality development in the new era, future works and development directions of maps and cartography need to be adjusted in time.

(1) The research of basic theories of cartography needs to be further strengthened in the new

period. The form, content, production, and service modes of maps have undergone significant changes, in the era of the Internet of Things, the Internet, and mobile networks, leading to the emergence of new concepts and types of maps such as Pan-map, micro maps, street-view maps, public-participation maps, new media maps, cyber maps, and robot maps. These new types of maps have broken through the existing definition of maps, enriched the form of map expression, and expanded the boundaries of map applications. Therefore, it is urgently necessary to redefine the definition, connotation, and extension of maps in the era of information technology, to fully clarify the architecture of map theory, technology, and application, to condense the forefront and core issues of cartography and geomatics, and to further develop the philosophical and modern theoretical system of map science.

(2) The intelligent system of digital cartography needs to be further developed. The process of digital map making requires extensive amount of cartographic knowledge and experience. Conventionally, map making strategies rely on the use of map templates and expert knowledge rules, which are predominantly established manually. However, the degree of intelligence of such templates and rules is limited, and is only able to address local automatic processing issues. With the advancement of artificial intelligence technology, machine learning, and deep learning, knowledge graphs are playing an increasingly significant role in map cognition, design, and analysis[11][11]. Furthermore, they provide comprehensive solutions for intelligent map compilation. During the map-making process, front-end data access, location acquisition, and image recognition are developing towards high-precision positioning, efficient processing, and high automation with the aid of artificial intelligence technology. The back-end map designing, cartographic processing, and information service should be deeply integrated with artificial intelligence technology. On the one hand, artificial intelligence technology can enhance the cognitive ability and spatial decision-making ability of complex systems and further improve the intelligence level of geographic generalization. On the other hand, new achievements in the field of artificial intelligence (AI) should be introduced into the field of map compilation and cognitive analysis to solve application problems that depend more on expert experience and personal preferences, such as creative map design, map style transfer, and symbol configuration and expression. Based on this, an online map-making intelligent system and platform that supports personalized map design should be further developed.

(3) The application field of thematic map needs to be further expanded and deepened. At the data level, the integration of geospatial big data has augmented the real-time dynamics of thematic maps, and the introduction of multi-model information such as videos, images, texts, and audios has provided novel ways of expressing thematic information. On the technical level, the advancement of virtual reality (VR), augmented reality (AR), and digital twin technologies has enriched the presentation of maps, allowing thematic maps to expand from two-dimensional to multi-dimensional, from abstract to concrete, and from static to dynamic. Examples of such expansion include the street-view (real-scene) map with various thematic elements, the holographic map that integrates spatial, acoustic, optical, and electromagnetic data in a

multi-modal manner, the high-precision map that facilitates autonomous driving, and the virtual game map that serves as the framework of metaverse scenarios. The acquisition, editing, organization, expression, and application technologies of these new maps require further deepening. The social service model that takes into account the service scenarios, populations, and construction costs also requires further exploration.

(4) The in-depth application of intelligence mapping needs to be further promoted. China is currently enhancing the intelligent construction of various industries such as transportation, environmental protection, industry and commerce, culture and tourism, education, and healthcare. This not only needs the basic support of an industry map but also needs the integration of industry big data from sensor networks, mobile internet, and service providers. Thereby, achieving intelligent map expression and decision-making services with dynamic monitoring and emergency dispatch functions. In the future, the focus of constructing an industry intelligent map should be based on China's National Fundamental Geographic Information Database, and integrating the static and dynamic data resources from the industry. Furthermore, aiming at the business operation process and key issues that need to be resolved, an intelligent service system for industry maps should be established, with functions of rapid information queries, dynamic monitoring of operational status, efficient schedule of emergency command, scientific analysis of planning decisions, and real-time dynamic automatic expression.

3.2 "Digital China" and "The Belt and Road" strategies providing new opportunities for the development of cartography and geomatics

The "Digital China" strategy is highly valued and supported by China, which was clearly proposed in the "Outline" of the National 14th Five-Year Plan on March 2021. In February 2023, the "Overall Plan for the Construction of Digital China Layout" was also issued. It further emphasized the importance and urgency of the construction, including the need to strengthen the data resource system and promote the deep integration of digital technology with the "five-in-one" construction of economy, politics, culture, society, and ecological civilization construction. As one of the means of representing spatial information, map has always been considered fundamental data for a country, which is crucial for national governance and security, and supports the development of various industries[12]. In light of the high-quality requirements of digital governance in the future, the fields of cartography and geographic information technology should realize effective integration, analysis, forecasting, and real-time expression of cross-industry, cross-region, multi-scale, and fragmented thematic spatio-temporal data. As a new generation of 3D map, realistic 3D China is a further upgrade of maps suitable for China's new development stage and helps promote the construction of digital China's spatio-temporal foundational infrastructure[12]. It is worth emphasizing that, the task of "building a green and intelligent digital ecological civilization" has directly pointed out the blueprint of "using digital technology to promote the integrated protection and systematic management of mountains, waters, forests, farmlands, lakes, grasses, sands, and to improve the three-dimensional "one map" of natural resources and the basic information platform of land space". This further demonstrates the important role that the "one map" of natural resources and the basic information platform of land space play in integrating various types of natural resource spatio-temporal data, promoting information expression, analysis, decision-making, forecasting, and achieving resource protection, dynamic supervision, and scientific management.

Since China proposed the "Belt and Road" initiative, more than 180 countries and international organizations have participated in it over the past decade, promoting mutual benefit and common development among the countries along the route. Currently, the initiative is undergoing changes, shifting from the early focus on large-scale infrastructure construction projects to emphasizing cooperation in new energy and digital fields, as well as jointly addressing environmental and climate challenges, further advancing the construction of a green "Belt and Road". In response to the new development situation, efforts are being made to strengthen the construction of national border and coastal maps, and establish a model for obtaining and integrating basic geographic information and dynamic spatio-temporal data for countries along the "Belt and Road", combine the design and expression of thematic maps, timely reflect the social, political, economic, environmental, and ecological status and changes of relevant countries, analyze the social, political, and economic exchanges between countries, support joint prevention and control and disposal of environmental and disaster emergencies among countries, summarize the achievements of the "Belt and Road" construction, and scientifically predict and present future development trends. All of the tasks mentioned above pose new challenges to mapping and cartography.

3.3 Challenges for the development of maps and cartography in the era of big data, Internet and artificial intelligence

(1) At present, spatio-temporal big data sources are becoming increasingly abundant, including remote sensing data that perceive geographical environments, environmental monitoring data, mobile trajectory data that perceive human social activities, social media data, consumer behavior data, and mobile signaling data, etc.[13]. The wide coverage of multi-type and massive spatio-temporal big data helps to meet the real-time and personalized service needs of different industries and users[14]. Through the mining of spatio-temporal big data, maps can better display the regularity and implicit characteristics and knowledge of things. For example, the use of human/vehicle trajectory data in the city, e-commerce platform review data, POI data of the Internet map, the swiping data of bus card and subway card in urban areas can be used to calculate the intensity of population activity, crowd activity satisfaction, commercial area activity and traffic activity, and analyze the influence mechanisms of urban commercial areas. Finally a comprehensive map of the spatial distribution of urban commercial vitality can be drawn[15]-[16]. However, the heterogeneous characteristics of multi-source spatio-temporal big data also add new

complexity and difficulty to the processing of map data sources[17]. The uncertainty in quality and the non-structured form of some big data also make it difficult to effectively integrate this data with fundamental geographic information data, which greatly restricts the application of data. Furthermore, privacy protection and security issues of data in the Internet environment also pose risks to the sharing and application of big data. Therefore, spatio-temporal big data provide a richer and more flexible source of data for map expression and service delivery, but they also bring a series of urgent problems that need to be addressed.

(2) The metaverse is a novel concept that has emerged in recent years. It is a virtual world constructed by humans using digital technology, which can interact with the real world through mapping or transcending it. Therefore, the metaverse is essentially a combination of the virtual world and the digital living world, with three types of construction methods: digital native, digital twin, and virtual-real symbiosis. In 2022, Google exhibited its "metaverse map" based on a 3D high-precision map. Apple, Facebook (now Meta), as well as Tencent, Baidu, and Huawei in China have all begun competing to develop their own metaverse maps. The reason why maps have become the entrance of the metaverse war is that 3D high-precision maps serve as the digital spatial base of the metaverse, which essentially digitizes the spatial information of people and their surroundings into higher dimensions, further constructing virtual scenes of twin or original worlds and enabling real-time collaboration within them[18]. Evidently, 3D high-precision maps will play a significant role in promoting breakthroughs in fields such as smart cities, digital culture and tourism, local life services, and generate numerous digital new consumption scenarios, thus enhancing the metaverse experience.

(3) With the rapid development of cognitive science, intellisense technology, and the Internet of Things (IoT), "intelligence+" has taken over from "Internet+" and "big data+" and is rapidly developing across the border[10]. Intelligent cartography, combined with such methods as deep learning, knowledge graphs, and intelligent interaction, presents four characteristics: crowdsourced data, user participation, model coupling, and visual analysis. The platform uses adaptive cartography technology to quickly create personalized maps that meet different levels of reading needs based on the characteristics of the data and the user's target requirements[19]. In order to achieve the deep application of intelligent cartography, natural language understanding and collaborative cognitive technology are used for human and machine interaction, and a cognitive interaction method with multiple modalities such as speech and text language is established to obtain users' map preferences and specific mapping needs. This, combined with the generative artificial intelligence (AIGC) technology, learns the characteristics of objects from crowdsourced data, and generates brand new and completely original map content, promoting the transformation of map-making into intelligent and popular cartography. The recently released Baidu Map Version18 is supported by the Wenxin Traffic Large Model built with generative AI technology, which can achieve end-to-end optimization of real-time traffic systems in characterization, perception, prediction, scheduling, and other functions.

3.4 Future prospects of cartography and geomatics

From a theoretical perspective, the rapid development of modern information technology and the growing social demand have brought new perspectives, new forms, and new content to cartography. For adhering to the principle of innovation and tradition, it is necessary to not only adhere to the essence and disciplinary characteristics of cartography, but also constantly explore and innovate on a theoretical level. In response to the development needs of the era of big data, metaverse, and artificial intelligence, it is urgently necessary to conduct basic theoretical research on intelligent maps, Pan-maps, realistic 3D maps, holographic maps, whole-spatial maps, metaverse maps, and map spatial cognition. This promotes the construction of a new theoretical system for cartography.

From a technical perspective, the intelligent mapping technology based on big data and artificial intelligence will become the core task of research. Spatial distribution pattern recognition and cartographic generalization supported by deep learning, intelligent driving and machine maps, and socialization services of spatial cognition, etc., are worth paying attention to. In the future, the key to the construction of spatio-temporal big data is to further extract information and optimize the quality of multi-source and multi-modal big data, implement the fusion of various types of spatial-temporal big data, establish a catalog of spatial-temporal big data with multiple scales, types, and ranges, improve the sharing mechanism of spatial-temporal big data, and provide flexible and efficient data support for intelligent map making. It is essential to strengthen the matching and integration of spatial-temporal big data with China's National Fundamental Geographic Information data, Tianditu (Map World) data, etc., optimize the spatial quality of big data, and enrich and expand the service content and scope of map making. On those bases, according to the requirements of intelligent map making, cutting-edge technologies such as machine learning, deep learning, knowledge graph, and generative AI should be fully applied[19]. Data analysis and feature mining are carried out from the perspectives of supply side (data) and demand side (user), so as to realize the effective connection of mapping goals, personalized needs, data resources, and automatic map-making technology, and establish a systematic path for implementing intelligent map making.

From an application perspective, the development of intelligent map-making technology will promote greater emphasis on intelligent map services in cartography. On the one hand, this will provide automated and user-friendly map services, such as route planning, navigation, tour guides, shopping guides, education, and social interaction for individual user's daily life, learning, and work. It will also explore virtual immersive map services in the metaverse. On the other hand, focusing on the management service requirements of governments and industries, it will strengthen the basic supportive role of map spatio-temporal big data in "urban brain" data resources and promote the in-depth application of intelligent maps in industries such as smart city, smart transportation, smart tourism, smart mine, smart education, smart healthcare and other industries.

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