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REVIEW ARTICLE

Some thoughts on deep learning empowering cartography

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ABSTRACT

Cartography includes two major tasks: map making and map application, which is inextricably linked to artificial intelligence technology. The cartographic expert system experienced the intelligent expression of symbolism. After the spatial optimization decision of behaviorism intelligent expression, cartography faces the combination of deep learning under connectionism to improve the intelligent level of cartography. This paper discusses three problems about the proposition of "deep learning + cartography" . One is the consistency between the deep learning method and the map space problem solving strategy, based on gradient descent, local correlation, feature reduction and non-linear nature that answer the feasibility of the combination of "deep learning + cartography"; the second is to analyze the challenges faced by the combination of cartography from its unique disciplinary characteristics and technical environment, involving the non-standard organization of map data, professional requirements for sample establishment, the integration of geometric and geographical features, as well as the inherent spatial scale of the map; thirdly, the entry points and specific methods for integrating map making and map application into deep learning are discussed respectively.

Keywords: Cartography; Artificial Intelligence; Deep Learning; Graph Volume Learning Model

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1. Introduction

As a visual expression of spatial phenomena, map is usually known as the second language of geoscience research. It plays the role of analysis, expression and communication, transmission in exploring the laws of geoscience characteristics, revealing the mechanism of geographical process and mining spatial distribution patterns. From the perspective of semiotics, maps with spatial cognitive expression symbols as the main characteristics, together with text symbols representing language and digital symbols representing quantity have become the three major cultural tools for people to recognize the world[1]. Driven by new technologies such as network technology, big data analysis, artificial intelligence and multimedia visualization, the connotation and extension of cartography have been greatly expanded, resulting in cartographic tetrahedron[2], Pan map[3], Scene science[4] and other concepts. The scope of cartography has changed from the traditional real world to the virtual world. With the expansion of Pan space such as cyberspace, the map audience object is developing from human services to intelligent machines at the same time, generating the concept of holographic high-precision navigation map[5].

In the new technology of cartography, a prominent trend is the combination of map and artificial intelligence, which is manifested as machine learning, deep learning, knowledge map playing an increasingly important role in map cognition, map design and map analysis. With the support of intelligent technology, decision-making ability of map spatial has advanced cognitive ability of complex systems. Creative design of map supported by deep learning can transfer the knowledge and experience of map experts, and greatly improve the artistic expression of maps. In making decisions in space, travel navigation and landscape design, map combined with in-depth learning and knowledge maps can better simulate human thinking in spatial problem identification, judgment and prediction. From the perspective of discipline system, the cartography belonging to the secondary branch of Surveying and Mapping Science and Technology combined with intelligent technology is an important component of the overall development of surveying and mapping technology from digitization to informatization and then to intelligence. In the technical chain from earth observation data acquisition to spatial location information service, cartography is located at the back end. And the positioning acquisition and mage recognition at the front end is oriented to high-precision positioning, efficient processing and high automation with the support of artificial intelligence technology. The mapping processing and information services of back-end should also be connected to artificial intelligence technology to realize the integration of artificial intelligence and surveying and mapping technology.

Map making and application in the era of manual technology depend on people's highly intelligent behavior[6]. In the selection of cartographic data sources and feature extraction, creative design of map symbols, feature abstraction of map generalization and the model decision-making of map analysis needs the deduction and induction supported by spatial thinking, the support of cartographic knowledge rules the constraints of spatial cognitive principles and the control of scientific principles in the field of Geoscience. Hence, cartography is considered to be a discipline with highly intelligent characteristics[7]. For this reason, the development of cartography has been closely followed by artificial intelligence (AI) technology. With a view to introducing new achievements of AI into the field of map making and cognitive analysis, the creative design ability of computer cartography system will be close to human brain behavior. And the map analysis system will have the intelligence level similar to human brain.

Artificial intelligence is a new technology science developed for imitating, extending and expanding human's intelligent method, technology and application system. Since the concept of artificial intelligence was put forward at Dartmouth conference in 1956, a variety of intelligent expression and intelligent computing models have been produced. First, the "symbolism" based on rule-based reasoning had been created. And then the "behaviorism" imitating related intelligent life processes and physical processes was proposed. Now it has been developed into "connectionism" that mimics the complex structure of neurons[8]. As a special application field of AI, cartography has a positive response to the application of AI related technical achievements in different stages of AI development, and shows the unique spatial intelligent technology of cartography.

In the early stage of artificial intelligence "symbolism", it is believed that human's intelligent behaviors such as decision-making and reasoning are based on the deduction of knowledge rules. And rules are composed of a series of the most basic logical unit symbols. Based on mathematical-logic theory, an expert system is constructed. It composed of rule base, inference engine and user Interface, which is a typical representative of intelligent expression of "symbolism". Driven by the intelligent technology of "symbolism", in the 1990s, the research on expert systems for map making and analysis was also carried out in the field of cartography. It discussed the projection decision-making of map, conversion from spatial data to map symbol, map symbol design and so on. The earliest batch of doctoral dissertation studies in the domestic cartography discipline also focused on the exploration of this issue[9,10]. And also a thematic map cartography expert system had been launched[11], which had automatic map color design, symbol selection and other functions. However, the cartographic expert system does not substantially solve the problem of intelligent cartography. Knowledge extraction and establishment are far from the real expert knowledge that the human brain completes the same behavior. A perfect map mapping rule base cannot be established only by specification for Cartographic Schema, experts' oral investigation and limited case analysis. There is a lack of rule description tools for deep informal expression. At the same time, the inference engine based on mathematical logic is also inadequate in rule deduction[12].

Under the influence of cybernetics, artificial intelligence “behaviorism” believes that evolution of life and physical processes and control behaviors can be used for intelligent simulation. Integrated the working principle of neural system with information theory, control theory, logic and computer, it can simulate intelligent behaviors such as self-optimization, self-adaptation, self-stabilization, self-organization and self-learning so that a series of optimization algorithms for simulating the evolutionary process of life and the physical control process have been introduced. Combined cartography technology with “behaviorism” intelligent model, it conducted research on optimization decision-making for uncertain problems such as symbol design, surface configuration, and graphic synthesis and simplification[13] in cartography. And, based on a series of optimization algorithm ideas such as genetics, ant colony, immunity, simulated annealing, etc., the map space decision-making research was carried out ideologically[14]. It is used for map space land locating the development trend of space-time phenomena predicting, allocation of spatial pattern optimizing, automatic configuration of map annotation[15–17] and etc. These intelligent decision-making studies are relatively fragmented. Different “behaviorism” intelligent algorithms are adopted for different decision-making behaviors, and there is a lack of complete strategies to systematically solve intelligent problems in cartography. Moreover, the intelligent simulation of this behavior process is lack of explicability, and the logical connection of optimal control cannot be revealed from the mechanism.

AI “connectionism” focuses on the signal transmission connection between neurons through the simulation of complex neuron structure, and then puts forward one of the most dynamic AI methods at present[18], which produces a machine learning method represented by deep learning. It shows the powerful intelligent simulation effect of deep learning in playing chess, image feature recognition, natural language processing and other fields. The gradient descent, local correlation and strategies to enhance computing power such as feature dimensionality reduction are used in “connectionism” intelligent model, realizing the high-efficiency simulation computing of intelligent behavior in complex systems[19]. The combination of cartography and in-depth learning is an effective way for the intelligent development of cartography. Some results obtained in the previous research show that in-depth learning used in the feature recognition of spatio-temporal big data in the field of cartography[20], decision reasoning of complex mapping process[16], intelligent cognition of map spatial pattern[21], the transfer of artistic creativity in map design[22] acquires a good development prospect. In exploring the rules of map space knowledge, participating in autopilot navigation and rapid construction of high-precision maps[23], it also can play an active role. On the other hand, the combination of deep learning and cartography faces many challenges. The combination of deep learning and different application fields needs to consider the particularity of the problems in this field, including the structure and organization of data, preparation of samples, specific service target requirements and other conditions. It is also a map of visual information. Compared with another kind of visual information image, the data organization of the map is non-standard, and the collection of vector samples serving the learning model is difficult, resulting in the research of map deep learning lagging behind the research of intelligent processing of remote sensing images.

In order to promote the establishment of intelligent surveying and mapping technology system and drive the effective combination of deep learning and cartography, this paper will start from the feasibility of the combination of deep learning and cartography, the challenges it faced and the development trend to discusses the method of combining map making and map application with deep learning.

2. Deep learning method and the idea of solving map space problems

As a representative of the "connectionism" intelligent model, deep learning (DL) is a machine learning method that simulates the connection and signal transmission of neural networks in the cerebral cortex. DL obtains the inherent laws of learning sample data through the training of case samples, and its ultimate goal is to enable machines to have the ability to learn and make decisions like humans, and to recognize features, types and structural information. It is built by adding more connection layers (hidden layers) to the traditional neural network model[18]. DL model has experienced several milestone breakthroughs in the development of AI. Feedforward neural network and perceptron FFNN have laid the foundation for DL network connection model[24]. Back propagation network model BP uses gradient descent idea to greatly improve the efficiency of model fitting[25]. Convolution network model CNN uses local correlation idea to better extract vector feature information[19]. DL model is highly valued in the field of AI, and new models emerge in endlessly, which are oriented to feature extraction, target classification, identity recognition and process forecast, etc. From the perspective of application, these models can be divided into different DL models such as linear structures matrix array structure, tree structure figure structure, etc. according to the data structure. For example, RNN, a cyclic network model based on linear structure, long and short memory network model LSTM, CNN Convolution network model based on array structure, GCN Convolution network model based on graph structure, which can realize the classification of cartographic data in map making, selection of visual symbols, the decision of map generalization operator, graphic art style design and other requirements, realizing the prediction of space-time information, division of spatial pattern, spatial pattern recognition, and etc. in map application analysis.

In essence, DL model is a decision-making method for uncertain problems, which is similar to classical statistical learning (regression analysis. Markov chain, etc.) and traditional machine learning (support vector machine. Random forest method, etc.). The model can be understood as the solution of a highly abstract connection space constructed by multilayer neurons. A series of strategic ideas are applied to the fitting calculation of the mathematical space to ensure the computational advantage of the model. When DL model is applied to solve cartographic problems, it can be considered as the combination of two spatial problems, that is, the combination of abstract neural network space and actual map space. Map space is an entity of the geographical world. Map space is a mapping representation of entities, phenomena and processes in the geographic world. In the description of geographical phenomena, the definition of spatial relationships, and the expression of time-space processes, a series of theoretical research and practical exploration have established the rules and laws of geography and cartography as the ideological basis for solving the spatial problem. When studying the combination of cartography and deep learning, it is necessary to investigate whether the two ideas of spatial problem solving agree with each other.

There are many types of deep learning models, but they are all based on the idea of connectionism. They use some common strategic principles and geographical space in solving abstract space problems. The idea of solving map space problems is consistent, with the following four points.

2.1 Gradient descent

Gradient descent is considered as one of the core ideas of deep learning[19]. In the multi-layer connection of neural networks, in order to find the model fitting parameters that minimize the error, the iterative method is used to adjust the parameters repeatedly to ensure that the output results in the training approach to the samples.

How to modify the parameters to make the result approach quickly? Using the idea of gradient descent, the steepest gradient direction is determined by first-order differential calculation. Based on the back-propagation process, the weight parameters on the node connection are modified. It is worth noting that when interpreting the idea of gradient descent in the field of AI, contour diagrams are almost used to interpret the process with the direction of slope (**Figure 1**). Contour map is a classic visualization method to express topographic relief in map space. The idea of gradient descent embodied in the steepest slope plays a direct role in the navigation path search of topographic map. In addition, in the extraction of structural features of DEM bottom line, the accumulated calculation of water catchment tracking the direction of the steepest slope in eight adjacent areas adopted by D_8 algorithm is also useful in the idea of gradient descent [26]. It can be said that gradient descent is also the basic principle followed in the problem solving of map space, which is consistent with the gradient descent of abstract space followed by DL.

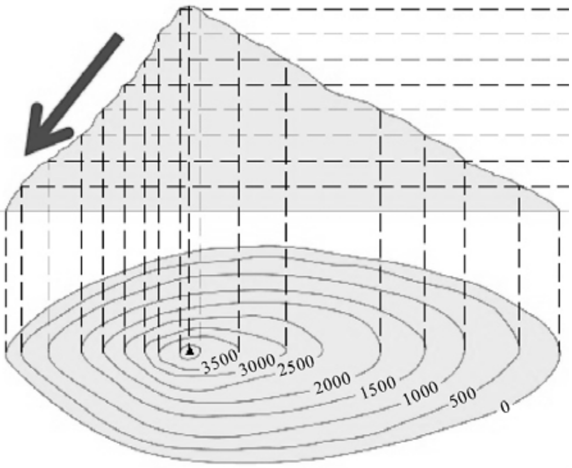

Figure l. Explanation of the idea of gradient descent in DL model with contour line.

2.2 Local correlation

Deriving new vector features through convolution is an important breakthrough in DL, especially convolution based deep learning. The hidden features of neurons can be revealed through the convolution operation of specific convolution kernel function and original function, and different features can be revealed through different convolution kernel operations. CNN model applied in image feature recognition benefits from convolution operation, and others include convolution operation on linear structure, convolution model GCN on graph structure including convolution operation in spatial domain, convolution operation of Fourier transform in frequency domain[27,28]. The basis of convolution operation is the local correlation of neuron space. Whether it is the neighborhood correlation of pixel matrix space or the node neighborhood correlation of graph structure, it reveals the characteristics of the current structural unit through the characteristic operation of neighborhood units within a certain range, which reflects the "near Zhu Chi" the effect of "those who are close to the black are black". The idea of local correlation in convolution DL model is too familiar to researchers of geographic information or cartography. The first law of geography is the description of this idea[29]. The autocorrelation of a single phenomenon in map space can be measured by Moran's I coefficient, and the correlation between multiple phenomena can be calculated through the correlation analysis of spatial statistics[30]. The spatial correlation analysis of map is essentially consistent with the local correlation based on the convolution operation of deep learning. Both of them work in the spatial neighborhood and decay with the expansion of distance. The local correlation reflects the consistency of the two spatial problem-solving ideas.

2.3 Feature dimension reduction

In the DL model, the vector describing neurons is multidimensional. One of the goals of training and learning is to reduce the dimension of the vector, express its typical features with simple vectors, and adopt the eigenvector of the matrix. PCA, the method of eigenvalue decomposition and principal component analysis to realizes feature dimensionality reduction. And in the pooling operation of the learning model, it also has the function of feature dimensionality reduction. It can be said that feature dimensionality reduction is an important strategy of deep learning process operation. This idea also exists in the solution of map space problems. The complete description of map data includes space, time and semantic three-dimensional features, further refining each one-dimensional feature can derive multidimensional subsets. The abstract generalization of map generalization is the complex multidimensional space, time, and the simple expression results of semantic data after synthesis obtained through the dimensionality reduction method, which reflects the simplified characteristics of the main body of map information. For spatial dimension processing alone, map projection in cartography is a typical dimensionality reduction method, that is, the spatial 3D model is reduced to two-dimensional expression. As the core content of cartography, map projection has a perfect dimension reduction transformation method in feature dimension reduction such as transforming the model, deformation measurement, and etc. Therefore, the two spatial problem-solving ideas are consistent in feature dimensionality reduction.

2.4 Nonlinearity

In the DL model, the model fitting of neuron space is faced with a complex system. In order to reflect the complexity of solving the problem, the compulsory measures of nonlinear processing are taken, so that the signal value of the front and rear nodes is not a simple linear transformation. The activation function in DL model adopts sigmoid function and the form of Tanhx function destroys the linear transformation, and the simple linear transformation is intentionally modified by nonlinear adjustment of ReLU (rectify linear unit) to prevent over fitting in learning. The idea of non-linearity is also reflected in map geographic information processing. The principle of spatial heterogeneity describes that the spatial characteristics in different regional environments are different[30]. Spatial correlation under linear structure cannot be constructed simply based on distance. The principle of spatial heterogeneity is also known as the second law of geography, which shows the significance of this principle in solving geographical problems. Therefore, in dealing with the idea of nonlinearity, the two strategies for solving spatial problems are consistent.

Based on the above analysis, there is a gradient descent in the problem solving of DL in neuron abstract space and in the real space of cartography, local correlation, the application of the idea of feature reduction and nonlinearity, showing that the idea of solving the problem of map space through DL method is consistent. This also finds the feasible conditions for the combination of cartography and DL.

3. Application of deep learning in map making technology

Cartography includes two branch tasks: map making and map application. The former completes the transformation from number to graph, and the latter completes the analysis and application from graph to number (the application analysis of map is represented by the processing based on map to obtain the spatial knowledge expressed by number). These two branch tasks can be combined with DL to improve their intelligence level. Due to the different way of combination, the contents are different, so it need to be discussed separately.

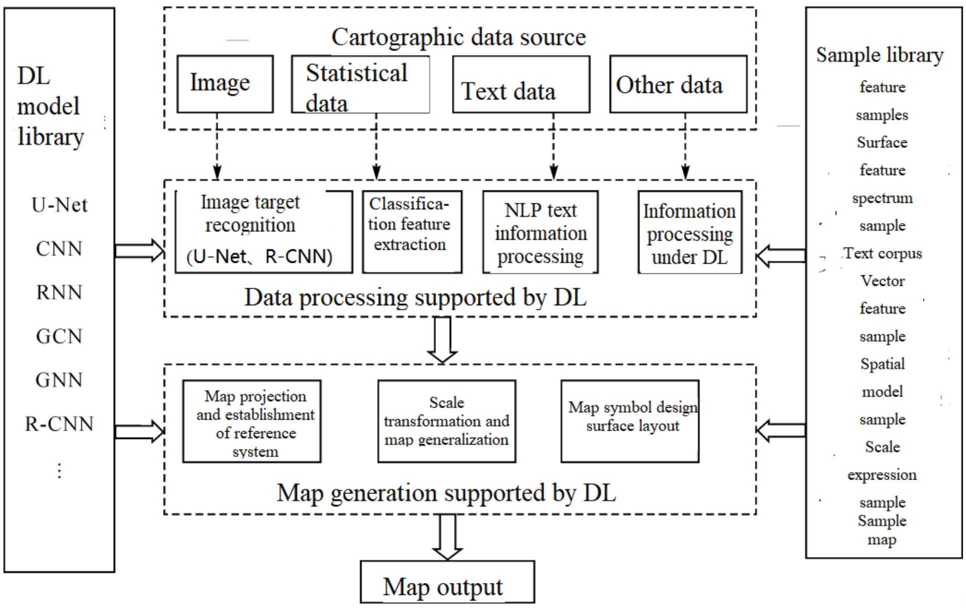

Figure 2. Map making process supported by DL model.

The design and production of maps is a complex system, involving the integrated processing of various types of data sources, spatial feature analysis and extraction, map projection transformation, scale transformation and feature abstract generalization, symbol design and visual expression[31]. How to seek the application of new technology and improve the intelligent level of computer cartography system has always been the goal of the field of cartography. DL technology can run through multiple links such as slave data processing, graphic design to map output. At present, there are many models in DL to realize feature extraction, identification, target classification, process prediction and other functions, which are also required in the process of map design and production, according to the technical process of map production and the conditions of DL model. The goal is to select a suitable universal DL model, and complete the processing and graphic transformation of map data through targeted improvement and combination. The application of DL model needs to rely on various forms of sample database, which is similar to the judgment and recognition ability of human brain under the training and learning of sample cases. Therefore, it is also an important work to establish various sample databases accompanying the cartographic process. The technological process of mapping supported by DL is shown in **Figure 2**.

Map making includes two aspects: cartographic data processing and graphic generation. In graphic generation, three technical processes of map making should be completed: map projection, map synthesis and map symbol design. These branch tasks can be integrated into DL methods to varying degrees to complete analysis and decision-making and intelligent processing. The processing of the following three aspects is the key to the combination of DL and map making.

3.1 Processing of cartographic data source under DL model

The data source of cartography is very rich. Especially in the big data environment, all kinds of earth observation data, social perception data, professional sensing data, network self-media data, VGI information, etc. provide a large number of data sources for map mapping[31]. These data have various forms, many types and complex structure and at the same time rich information content is hidden in it. The traditional data processing methods are not competent for the challenge of big data processing. Processing with decision-making and judging behaviors, such as classification, feature extraction, and graphic recognition of cartographic data, is the entry point for DL applications. Image data, auditory signal data and text data processing is an important data object of current DL model processing. A large number of special DL models have been produced to realize feature extraction, semantic understanding, automatic translation and other functions. Some of these data processing works are consistent with the requirements of map mapping tasks. And some of them can spatialize the general processing. The improvement of graphical features is incorporated into the processing of cartographic data. According to the form of mapping source data, different target functions, it can select the appropriate DL model to process the mapping data source and complete the cleaning of mapping data, classification and knowledge discovery.

As an important data source of cartography, remote sensing images are applied in DL modes such as U-net and R-CNN to implement ground feature recognition of image information, semantic segmentation and feature extraction[32,33] , realizing the extraction of vector targets as the input of map mapping. The understanding and information extraction of text data is an important work of cartographic data processing in the big data environment, which involves the understanding and recognition of place name information, feature extraction of self-media text information, POI semantic information extraction and classification. NLP, as an important branch of DL research, has produced a large number of NLP model methods, which can be incorporated and improved for geographical names, POI semantics, the understanding and processing of spatial language to realize the intelligent processing of cartographic text data. The socio-economic statistical data in the process of mapping is usually the main data source of thematic map making. And the classification and grading of thematic statistical data to realize the division of spatial patterns, spatial pattern recognition and temporal and spatial trend prediction are usually the goals of such data processing. The models of deep learning methods serve this goal including spatial clustering GNN, spatial kernel density analysis CNN, etc. In addition to expressing the spatial positioning and distribution of geographical phenomena, the map is not only answers “Where?” “What is it?”. It gradually turns to the deep-seated spatial data processing combined with the knowledge in the field of Geoscience, from the spatial feature mechanism. The logical answer of spatial causality is “how about it?” “Why?”. This broadens the extension of map expression, and expands the deep combination of cartographic data source processing and Geoscience Knowledge, which will be with decision-making. The DL model of judgment has a new application. Based on the graph convolution network model GCN and the cyclic network model RNN, on the basis of the travel trajectory sample training, the travel routes of foreign vehicles and pedestrians are analyzed to predict the location and make a traffic prediction map[34]. Using the DL model to make comprehensive judgment, correlation analysis and trend prediction for spatial data. And it will be an important trend in the future development of cartography technology.

3.2 Scale transformation and map synthesis under DL model

Map generalization is an important technical link in map making, and it is also a unique form of abstract spatial thinking of maps. Through the abstract generalization of spatial and semantic information, the main characteristics of the spatial distribution are summarized to realizes the scale transformation from large-scale to small-scale expression[37]. Map generalization is considered to be a highly intelligent behavior with spatial abstract thinking. And its combination with AI technology is the most active in the cartographic technology system. Early research on expert systems attempted to achieve intelligence in many aspects, including spatial conflict detection, integrated operator scheduling, integrated process control and result quality evaluation, through the judgment and decision-making of map synthesis rules[38,39]. But the difficulty of establishing expert knowledge rules stops the map integrated expert system. From a new perspective, deep learning opens the door to the intelligent solution of map synthesis. Based on the case learning training of a large number of scale expressions, the rule knowledge of graph simplification, information abstraction, and feature generalization is obtained, and then the scale transformation of the input new data is implemented through the learning model. In the past, rules were used to establish the conditions and reasoning mechanism for map synthesis. After the implementation conditions of map synthesis were defined, the processing of special graphics, special contexts and special structural relationships would always be encountered, Therefore, the continuous patching of the main conditions in order to improve, not only destroys the integrity of the map synthesis occurrence conditions and the formalization of the calculation model, but also cannot guarantee the exhaustion of other conditions due to the complex rule expression. Deep learning automatically obtains various graphic features through learning under the training samples. As long as the representativeness and scale of the case samples are sufficient, the rules of map synthesis expression in the context of structural relationship and context can be exhausted in theory. At the same time, the domain knowledge of cartographic experts can also be defined and quantified in DL model, control of learning model (selection of convolution kernel. The definition of convergence conditions, etc.) can be embodied.

The underlying application is the design of map synthesis operators supported by the DL model, which completes operation algorithms such as shape simplification, merging of adjacent features, and conflict relationship shifting. Based on different data structures and different DL models, there are already a number of such operator appeared. Sester, Feng and Thiemann[40] converts map data into grid structure, and uses similar image processing to realize the synthesis of building shape supported by u-net model. To solve the same problem, Yan *et al.*[41] applies the GCN encode method of graph convolution coding and decoding to intelligently recognize the shape template and realize the simplification of shape. Both methods can reach the shape recognition level of professional cartographers to a certain extent. Yan *et al.*[42] realizes the distribution pattern clustering of buildings in the block through the graph convolution GCN model, which provides a decision basis for map synthesis and merging. The graph convolution method based on frequency domain Fourier transform can better detect the neighborhood structure relationship. The high-level application is manifested in the scheduling and suitability decision-making of DL model in map synthesis operator. The intelligent decision-making process belongs to the macro level and takes into account more preconditions and contexts. Relevant research has applied the back propagation network model BPNN to establish a building synthesis method[43], which realizes the optimal decision-making among the four algorithms, and selects the optimal synthesis algorithm for different graphic feature conditions. The early research on agent agents for the intellectualization of map generalization[39] is in the selection of generalization operators, and condition judgment. Some experts believe that the application of DL in map generalization in the new era is a new agent[16].

3.3 Map symbol design and visual style expression under DL model

Map making is a processing process with artistic creative design. The freehand drawing of map symbols, the style of map format, and the situation of spatial graphic organization all contain the content of map art creative design. In addition to reflecting the scientific nature of spatial projection models and geoscience knowledge, and the operability and high-efficiency technicality of data processing graphics generation, it also takes into account the aesthetic feelings and artistic characteristics of the audience's visual identity. The three-dimensional unity of science, technology and art is a map disciplinary characteristics DL uses learning methods to extract style patterns in images and audio in visual information and auditory information processing, which is considered to be one of the outstanding achievements of DL. It can not only find the artist's creative style in the image, but also migrate to new artistic creation, design works with similar styles by means of imitation, and simulate and express the creative characteristics of a specific cultural era (**Figure 3**). In map art design, the rendering style of map layout can borrow the style mode of image extracted by convolutional neural network CNN[44], so as to realize the migration of specific art style to map layout design. Gan, the generative countermeasure technology in deep learning, can complete similar functions[45]. Some hand drawing functions (pencil drawing) and manual watercolor design) can also complete the design of personalized map symbols and graphic layout through this in-depth learning method[46]. The application of DL technology makes map design introduce strange artistic forms under the condition of ensuring the scientific content, and finds a new way for the combination of science and art. In addition, the suitability selection of map visualization symbols can also be completed with the support of deep learning. A large number of map symbol templates have been accumulated in the long-term map design. It is a typical decision-making problem that how to choose appropriate visual symbols from a large number of symbol styles for specific mapping data in a variety of statistical chart forms. It is a new idea of map design in the context of big data to realize symbol selection through sample training and deep learning.

Figure 3. The transfer of map visualization style.

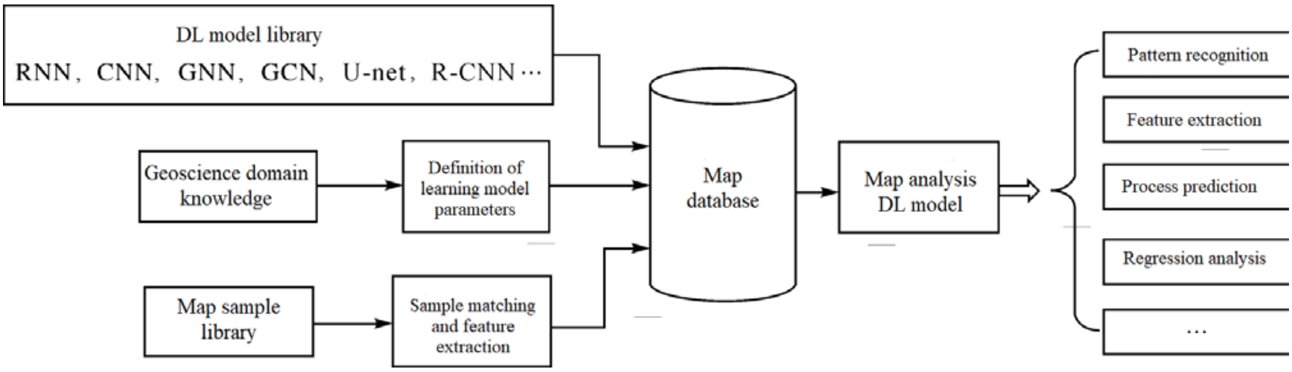

Figure 4. Map analysis process supported by DL mode.

4. Application of deep learning in map analysis

Map application analysis is another task of cartography technology, involving a large number of decision-making analysis processes such as identification, judgment, and reasoning. It is another combination of DL applications in cartography. The map analysis process supported by DL model depends on the support of geoscience domain knowledge and map feature sample database. The flow of this analysis is shown in **Figure 4**.

According to the difference in the types of map analysis, select the appropriate learning model from the DL model library for different forms of analysis, such as pattern recognition, process prediction, feature extraction, regression analysis, etc. The learning model in DL model base has the function of general decision analysis. When it comes to the analysis of map field, the essence is to establish the mapping relationship between the abstract neuron space in the general model and the entity space in the actual map. It is necessary to establish the correspondence between neurons and entities in map space in DL model, and the correspondence between the description vector of neurons and the characteristics of geographical entities. Neurons in map analysis DL models can be geographic entities, target group structures, snapshots of spatiotemporal processes, or spatial division units., whose organizational structure can be abstracted as linear tables, Matrix, tree structure and Graph structure. In the DL model base, there are learning models corresponding to different data structures. Data structure and task objectives are often the basis for selecting DL models. At the same time, the vector definition of these units requires geoscience expertise to establish the influencing factors, correlations and contextual conditions of their decision-making goals, and spatial cognitive science to establish cognitive gestalt parameters such as the Gestalt principle. Different from image recognition, the parameter definition in the DL model mainly relies on three chromatographic channels, RGB, to complete image understanding and feature recognition. The vector descriptions of learning models such as map-based pattern recognition and process prediction become more diverse, depending on the problem of decision analysis, it often requires the support of professional knowledge in the fields of geology and cognitive science[20].

As the basis of learning and training, map sample database plays an important role in the DL model of map analysis. The types of map samples include spatial patterns of different spatial distribution characteristics, land use types, distribution patterns, and geographically divided landform types, wetland types, economic functional areas, and urban functional areas. After a typical sample with a certain scale trained, the DL model has the ability of self-decision, and can judge its partition, type, characteristics, etc. for the newly input data by itself.

There are deep differences in the combination of map-based decision analysis and geoscience domain knowledge, which can be divided into shallow spatial analysis mainly based on geometric features of graphics, and deep spatial semantic information joint analysis of deep geoscience domain knowledge in-depth integration. The former mainly completes the decision-making analysis of geometric patterns, main features, spatial patterns, and regional correlations, etc., while the latter belongs to the specialized analysis in the field of geology, involving the division of functional areas, the prediction of temporal and spatial process trends, and the extraction of geoscience laws, etc.[20]. This analysis process is also the embodiment of the data intensive fourth scientific research paradigm generated by big data. DL model is data-driven, and the training based on samples which reveals the spatial distribution knowledge and spatiotemporal evolution law. The application of DL model in map analysis requires low data content, which can be completed on the basic point, line and surface geometric feature data. Based on the convolution model, CNN can realize the recognition of "problem map"[47]. Similarly, CNN uses the convolution model to select the map type data from the mixed graphic and image data[46]. Yan *et al.*[42] used the graph volume GCN model to realize the feature recognition of whether the building distribution is standardized or not; literature[48] is about orthogonality in urban street network. Radiation and other different patterns are recognized (**Figure 5** Shows the application of graph convolution learning model in road network orthogonal pattern recognition); He *et al.*[49] used image recognition DL model to complete the recognition of overpasses in the street network. These studies are all realized on the basis of geometric data, and the demand for domain knowledge is almost zero. For the latter DL model facing geoscience domain knowledge, comprehensive learning decisions are required, and the close combination of geoscience domain knowledge and DL is required. At present, the first active field of application in this field is to identify different functional areas of cities through DL in time[35,50]. This combination can introduce the characteristics of geoscience through the definition of the neuron vector, take into account the domain knowledge in the gradient descent condition and select a specific professional convolution kernel in the convolution model, etc., so as to realize the domain knowledge control of the DL computing model. In addition, the targeted selection of sample types can also reflect the role of domain knowledge. Comprehensive analysis of map data, such as soil type, wetland type division, geoscience functional area division, etc., will be the development direction of deep learning in the field of geology[20].

5. Challenges and development prospects of "deep learning + cartography"

DL is a computational model that simulates human's intelligent behavior. When applied in different fields, the model needs to consider the nature of the target problem in the field, the mechanism of intelligent decision-making, the structure and organization of input data, and the preparation of samples. At present, when DL is applied in several important fields such as image understanding, natural language processing, and chess games, it faces different challenges and challenges. And "deep learning + cartography" also faces challenges. Influenced by the specific professional characteristics and application environment of cartography technology, the unique problem of combining the two has arisen. Specifically, the challenges faced by "deep learning + cartography" are as follows.

5.1 Non standardization of map data organization

The data content of the map is composed of structured feature entities, and the types of geographical elements are rich. The structure relationship is complex, and the data organization used for map storage lacks the standard pixel matrix structure like image organization. The expression of map vector data needs to adopt different data structures for different features and tasks of different nature, including linear structure, tree structure, graph structure, etc., which are respectively used to describe the cluster target, layer structure target, network target, etc. of map vector data. When building a DL model for map analysis, we need to consider a variety of data structures, such as RNN model based on linear structure, CNN model based on matrix structure, Graph convolution model based on tree structure, graph structure GCN model, etc. In the pixel organization matrix structure of image data, the neighborhood relationship of the pixel and the feature description of the pixel are determined and standardized. However, the widely used graph structure in map representation, the dimension and feature description of the neighborhood relationship of its nodes are not fixed and belong to a non-standard data structure. The CNN model and its improved derivative models developed based on the canonical structure have achieved good results in image recognition and understanding. But it may be difficult to play a role in the face of map data. In DL research, as a rising star, graph-based DL model GNN, GCN[27,28], is expected to play an important role in map application and solve the problem of non-standard map data organization. River network in map data. Road network and buildings after dual transformation, POI point access structure, etc., can establish the graph structure through a certain form of transformation (the nodes of the graph correspond to entity units, and the edges of the graph correspond to neighborhood connections. As shown in **Figure 6**, GNN is established based on this non-standard graph structure. GCN model

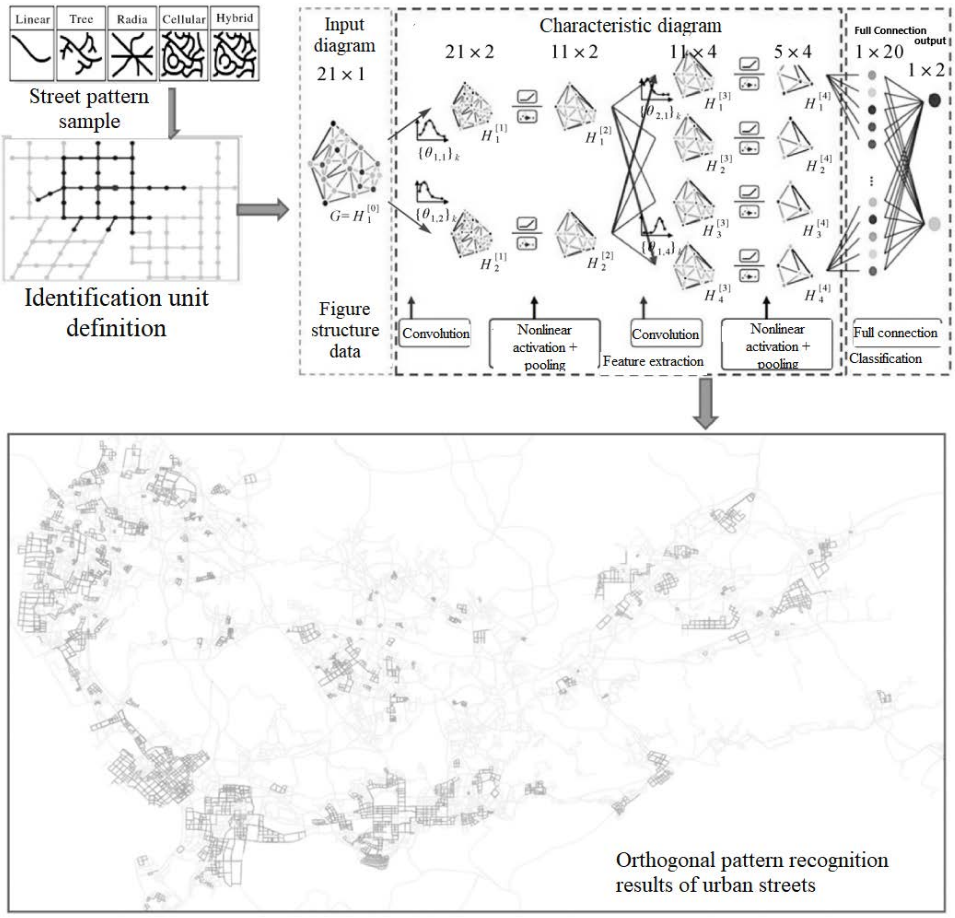

Figure 5. A convolution neuron network model to identify special street pattern.

5.2 Professionalism of map target sample annotation

The sample database is the basis of DL, and it is the training and learning of a certain scale of samples with representative characteristics that enables the model to have self-decision-making ability. The DL model is established in the map field, and the sample database it relied on includes spatial patterns of different spatial distribution characteristics, land use types, distribution patterns, and geographically divided landform types, wetland types, economic function areas, urban function areas, etc. The selection and labeling of such samples need to rely on human intelligent decision-making and judgment, and some require professional knowledge support, so it is difficult to establish a large-scale sample database in a short period of time. The samples for image recognition are mainly the familiar feature type identity judgment, such as animal head like cat, dog identification, which can be widely solicited through the ubiquitous network interaction and other methods, such as Imagenet sample library reaching tens of millions. Professional knowledge needs of map sample annotation. The professional knowledge requirements for map sample labeling and the uncertainty of typical feature recognition increase the difficulty of combining maps with deep learning.

5.3 Integration of geographical features and geometric features

Map is the graphical expression of geographical features, not the visualization of general geometric graphics, which contains deep-seated knowledge in the field of Geoscience. When building the map DL model, the vector description of neurons should consider not only the geometric structure of space, but also the knowledge of geoscience field. Geographical features and geometric features are integrated, and the vector description is often multidimensional. Relatively, the description of neurons in image recognition is mainly RGB three channels based on chromatography, which is much simpler. In map analysis, spatial cognition plays an important role in pattern recognition and feature extraction, while the definition and measurement of cognitive parameters have strong uncertainty. It is also a challenge to find appropriate parameters expressed by pattern rules.

5.4 Suitable map scale selection of learning model

Scale is an important feature of map expression, which reflects the level of abstract generalization of geographical space. In the establishment of map DL model, the scale feature, especially the granularity of data expression, is an important factor. Facing a specific intelligent decision-making goal, it is a challenging problem to choose which scale to express the map and which level of data granularity as the data processing object of the learning model. The ground object in real space has different geometric dimensions in different scale expressions, different levels of abstraction and semantic features at different levels, which will affect the neuron definition and vector feature description of the learning model. In addition, the over fitting phenomenon faced by the learning model is also related to the details of vector description. In the convolutional DL model, the establishment of the convolution kernel and pooling function is also affected by the data granularity.

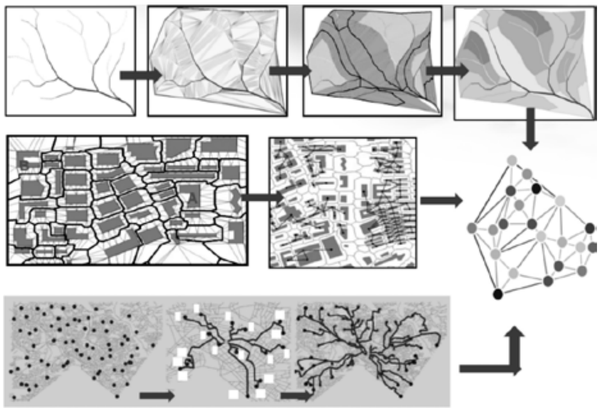

Figure 6. The map data abstracted to graph structure.

“Deep learning + Cartography” faces many challenges. With the in-depth development of DL technology, especially the development of interpretable DL model, the strategy of combining data-driven and domain knowledge driven will make a breakthrough. As location information plays an increasingly important role in intelligent decision-making, there are two trends in the future development of “deep learning + Cartography”. First, as a special DL learning data object, map will play an important role in spatial intelligence technology. At present, the data objects based on artificial intelligence DL include image, audio, video, text and other visual and auditory perception data types. As a map with geometric vector characteristics and topological structure expressed as position information, it is expected to join this series and become a new specialized data type, participating in the intelligent processing of DL From the analysis of Surveying and mapping technology chain, maps mainly come from images, but after structural processed, maps have significantly different characteristics from images in spatial expression, carrying more intelligent tasks such as spatial cognition and spatial reasoning than remote sensing. In the application of crowdsource network, the communication and transmission based on map location data are increasing day by day, just like images and audio, and maps have become specialized media data in spatial behavior and spatial language expression. Subsequent research in the field of AI will surely pay more attention to maps.

Second, the combination of the two shows that spatial intelligence will play an important role in the whole artificial intelligence system. Philosophically speaking, space is the carrier of all material phenomena. Space intelligence based on spatial positioning, reasoning, and decision-making plays a fundamental role in intelligent systems. In brain science research, it has always been an important topic to explore the classification of neurons in the cerebral cortex according to their intelligent functions, including all kinds of perception such as Linguistic. Emotional, etc. The 2014 Nobel Prize in physiology or medicine awarded the discovery of spatial location sensing neurons, which shows the prominent position of spatial intelligence (the discovery of brain neurons with other sensing functions is often reported, but it is not favored by the Nobel Prize). The importance of spatial intelligence in the whole artificial intelligence system will certainly promote the in-depth combination of "deep learning + cartography".

5. Conclusion

"A picture is better than a thousand words" is an interpretation of the spatial expression ability of maps. In order to achieve this goal, only the combination of map and intelligent technology can make the map have intelligent analysis. The ability of understanding can be truly embodied only by mining out the knowledge hidden behind the map. Cartography includes two major tasks of map making and map application, which have been combined with different technological achievements of artificial intelligence. Cartographic expert system has experienced the symbolism stage. At present, the spatial optimization decision-making in behaviorism stage is facing the problem of the combination of intelligent technology represented by deep learning under connectionism. On the one hand, there are many consistent strategies between deep learning and the solution of map space problems, which shows that the combination of the two is feasible; on the other hand, the combination faces a series of challenges. Compared with remote sensing image processing, which is a neighboring discipline of cartography, the data objects, sample establishment, parameter definition, and scale selection of map deep learning face certain difficulties. From the perspective of application, the deep learning of map is the application of universal DL model and spatial intelligent thinking. How to improve the intelligent level of deep learning, more and more experts gradually abandon the understanding of relying solely on data-driven, and turn to the strategy of parallel domain knowledge and data-driven. Based on this idea, map DL depends on the knowledge support of map experts and other geoscience experts, actively establish the intelligent problem of map space, integrate relevant domain knowledge into DL model, make the creative design ability of computer graphics system approach to human brain behavior, and make the map analysis system have the similar intelligent level of human brain, so there is a long way to go.

Conflict of interest

The author declared no conflict of interest.

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