Research on the Visualization of Spatio-Temporal Data

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Abstract. Spatio-temporal data visualization technology, with the help of data analysis methods and interactive technologies, help people to understand the information, knowledge, and wisdom behind the data more intuitively and efficiently. It has become a powerful tool for people to analyze and control data in the era of information explosion. This paper summarize visualization methods for spatio-temporal data and provides a classification of existing analytical methods, visualization techniques, tools and field of application, and briefly analyze the challenges and development trends of spatio-temporal data visualization.

1. Introduction
With the continuous cross-convergence of information technology with the political, economic, military, scientific research, and all aspects of human life, a huge amount of data has been created [1],[2],[3]. At present, the research on spatio-temporal data visualization mainly includes internet companies, academic institutions, media, and personal studios. The level of research in different fields and research directions are different10, it is necessary to conduct a summative study.

2. Visual Principle
Visualization technology is a discipline that utilizes the human eye's perception ability and human brain intelligence to visually interact with data to enhance cognition [13]. It maps data that is invisible or difficult to directly display into perceptible graphics, symbols, colors, textures, etc. Visualization technology can enhance recognition efficiency, and transfer it to useful information. Card [15] thinks that visualization is a series of conversion processes from raw data to visual forms to human perception and cognitive systems (see Figure 1):

- Data changes include data mining, data analysis, and data processing.
- Visual mapping maps data to visual structures such as maps, space bases, and virtual scenes.
- View transformation shows the visual structure on the output device according to position, scale, size, etc.
2.1 Raw Data Acquisition and Storage
After data acquisition completed, a high-speed data transmission mechanism is needed to transfer the data to a suitable storage system to be used by different types of analytical applications. Data storage solves the problem of continuous storage and management of large-scale data. With the in-depth development of global Earth observation systems, smart cities, and the Internet of Things, learning to use data effectively has become a trend.

2.2 Data Processing Analysis and Mining
Data mining technology is the process of discovering valuable, potentially useful information and knowledge from large, incomplete, noisy, fuzzy, and random large databases. The commonly used methods for spatio-temporal data mining include classification, clustering, association rules, neural networks, web data mining, and deep learning. Association rule is one of the most commonly used methods in data mining. It was first proposed by Wal-Mart in the United States for the analysis of the shopping basket. Its purpose is to find the relationship between different commodities in the supermarket customer transaction database. Applying association rules to public security intelligence analysis can help public security organs to discover the inherent laws of various crimes in various types of cases that have been collected. We need to develop a multi-dimensional, multi-structured, and complex data analysis methods and develop a rapid calculation model of spatio-temporal data[16], and realize rapid calculation of massive data.

2.3 Data Visualization
At present, the research on visualization mainly divided into two directions. First, the storage and processing of massive data machines, and the research of high-performance processing algorithms, storage, intelligent search, and data mining algorithms[18], etc. To screen, analysis, summarize, present the information are needed by decision makers, and updating them in real time based on the new generated data. On the other hand, based on people's needs, researching human-computer interaction and visual methods that conform to human cognitive laws[19].

The foreign MIT SENSEable City Lab is currently one of the best research institutes focusing on data visualization. There are Yuan Xiaoru’s team at the Peking University’s Visualization and Visual Analysis Research Group and the Institute of Software, Chinese Academy of Sciences’ Beijing Key Laboratory of Human-Computer Interaction. The current research on visual analysis of spatio-temporal data is still very preliminary, and the theory, methods, and technical systems in this field have not yet been formed [26].

3. Research on Spatio-Temporal Visualization Methods
Visualization appeared in 1980, and it has developed rapidly in the past decades. From the initial statistical charts to the combination with maps, three-dimensional display. Multidimensional data display with human-computer interaction technology to meet the user's virtual experience. Because people are no longer satisfied with the flat and static data visualization visual experience, more want to “deeper” understanding of a data and improve the clarity and aesthetic appeal of the displayed information.
Spatio-temporal data has the property of time and space. Nowadays, the commonly used methods for visualization of spatio-temporal data are mainly the combination of graphs and time axes, maps, etc. The commonly used techniques such as highlighting, scaling, fish-eye technology, association updating, and dynamic change [28]. Combined with human-computer interaction visualization technology, and combined with white background maps, three-dimensional virtual and other scenes for visual display, rich in forms, and easy for users to understand. The following Figure 2 gives a detailed description of the evolution of the visualization method.

3.1 Statistical Charts
Statistical charts are the earliest used visual graphs, which are consistent with human perception and cognition, are widely accepted. The basics are histograms, line charts, pie charts, etc. The size of the data is represented graphically, such as the length or height of the histogram, and the size of the data; the area of the pie chart represents the size of the data, and the data can be intuitively expressed. The proportion of information, easy to understand. With the ever-increasing form of visualization, visual forms such as character clouds, radar charts, chord diagrams, and relation diagrams have gradually emerged and are widely used. Such as the use of radar charts from the company's production, security, profitability, growth and liquidity in five aspects, the company's financial status and operating status of the intuitive, visual comprehensive analysis and evaluation.

3.2 Visualization Methods Combined with Map
Relying on today’s high-speed networks and big data background, to display spatial attributes of spatio-temporal data and the timeliness of data is particularly important. The combination of visualization methods based on map forms and industries such as GIS and maps has good visual effects, it can display the time and space properties of data. The common visualization methods combined with maps are as follows:

(1) Scatter Charts and Aggregation Charts. The scatter plot sets different magnitude symbols according to the data grade size, which can display the data size of a certain position intuitively and reflect the distribution of the data information. Space point aggregation mainly solves the problem of visual identification of a large number of points in the map. Aggregation charts not only reducing the load of the system for rendering massive data, but also allowing users to perceive the distribution characteristics of the massive target objects as a whole. Thereby providing the users with a good interactive experience. As shown in Figure 3, as the map zoom level changes, the points displayed on the map b aggregation to map a [34].

Figure 2. The evolution of visualization methodology
(2) Hierarchical Color Map or Regional Color Map. Dividing the data size or range of the study area into multiple data levels or sub-areas, setting discrete or continuous color changes according to different data levels or different sub-areas, displaying on the map area, can represent the density distribution of the data. Such as the density of the population, resources and other regional distribution; according to the distribution of the population's heat in different regions, the stress analysis of the primary school districts, the analysis of the new school location, etc. As Figure 4 shows the number of taxi trips from different regions to major hospitals in Beijing using this method. The advantage of this method is that it clearly shows the interaction volume and spatial distribution of other regions with specific regions [35].

Figure 3. China city administrative building distribution agglomeration diagram

Figure 4. Taxi interactive visualization to specific hospitals in Beijing
(3) **Heat Map.** The heat map shows the data from light to dark, from large to small, and concentrated to sparse (Figure 5 shows an example). The highlighted geographic area of the data set is highlighted. Heat map is used in many scenarios such as logistics, travel, and route recommendations. For example, social network applications use GPS devices to record user trajectory data and share location information through “sign-in” applications (such as WeChat, Weibo, etc.), and can recommend interesting tourist attractions and browse orders for users; the probability densities for a fixed time range and spatial position.

![Figure 5. a. Computer hotspot study map b. Cyber security incident map](image)

(4) **Route Migration Map and OD Map.** The Origin-Destination Line is the connection between the start point and the end point (Figure 6 shows an example). It is used to represent a certain relationship between two points, such as flight lines, population migration, traffic flow, and economic transactions. The maps represented by the OD lines are also called the route migration map. It can represent real-time logistics, real-time traffic management, location-based services, GPS navigation, and other applications involving time-space location change data to avoid congestion and improve efficiency.

![Figure 6. Flows of students and scholars from around the world](image)

(5) **3D Virtual Visualization.** With the continuous development and deepening of technologies such as 3D visualization, virtual reality, and 3D internet, people can use computers to process graphics, images, videos, sounds, animations, etc, to generate interactive 3D animations, dynamic simulations, and real physical effects. Simulation and strong visual impact enhance the user's perception of data. In recent years, research in three-dimensional visualization has mainly been divided into the following two aspects: first, dynamic visualization and visibility analysis of spatio-temporal data; second, virtual reality technology is used to simulate the terrain environment, and then interact and analyze. As shown
in Figure 7 below, the three-dimensional effect timeline dynamically evolves the distribution of BMI lipids in populations around the world for 40 years through dynamic changes through the time axis.

![Image of BMI distribution](image1)

**Figure 7.** The distribution of BMI lipids in populations around the world

3.3 Visualization technology Application Scenario

Under the two-wheel drive of demand and technology, smart city construction puts forward a “bigger” (extensive and detailed) requirement for urban big data, which means not only that the content is more comprehensive and detailed, but also more intuitive and more simulation and modeling. Structured or materialized and requires the integration of indoor space and outdoor space, the integration of ground space and underground space, the fusion of past data and current data, and the integration of current data with future data. Therefore, it is necessary to explore the visualization technology of geographic spatial data in smart cities. Smart city construction is inseparable from the visual work [39]. The following diagrams show two visualizations of two kinds of smart city construction (Figure 8 and Figure 9 shows examples).

![Image of smart city visualization](image2)

**Figure 8.** Underground passage combined with three-dimensional scene of ground environment
Figure 9. Indoor and outdoor three-dimensional scene

4. Human-Computer Interaction Technology
The interaction process is actually a collection of specific tasks. The user interactively analyzes the graphic elements in the visual interface according to the requirements, strengthens the user's control over the data, and establish a good human-machine relationship. Some interactive operations also include three-dimensional scenes and some interactive operations in virtual reality scenes, accepting user interaction feedback, generating new visualization results based on feedback, and implementing requirements such as queries and retrieval[44] to achieve visualization effects. The user interaction visualization method can dynamically and continuously express information, which is rich and vivid, and enables the user to have a more comprehensive and intuitive understanding of the visual expression of the data.

Integrated Card, was found by Shneiderman and Keim et al [45],[46],[47], dynamic filtering techniques, global + detailed techniques, pan + zoom techniques, focus + context technologies, multi-view correlation coordination techniques, and associated multi-view user interfaces(see Figure 10).

The natural interaction technology for Post-WIMP greatly enhances the naturalness of interaction methods[49], [50], [51], etc. such as multi-channel interaction, touch interaction, pen interaction, interactive technologies such as folding interaction, multi-touch, and gestures (see Figure 11).

The popularity of immersive head-mounted displays makes it possible to have an immersive stereoscopic visualization environment.

High-resolution video walls. The user stands in front of such a visual terminal. The more direct interaction method is through his movement, orientation, and distance as input for interaction. Researchers from the University of Copenhagen have used the concept of spatial relations as a starting point for the information visualization method of high-resolution video walls, and discussed the interactive solutions of information visualization on large screens (see Fig 12).

Figure 10. Pen plus touch interaction
5. Conclusion
With the advent of the era of big data, spatio-temporal data visualization has received increasing attention and visualization technology has also become increasingly sophisticated. However, there are still many problems in data visualization and they are facing huge challenges. It can effectively overcome the disadvantages of computer automated analysis methods, satisfy people's perception of information. The close integration of visualization and data mining, human-computer interaction are, high-dimensional data, and virtual reality technology are important development direction of visualization research. The integration of spatio-temporal data, will fast and efficient processing, the visualization of big data to create matching psychological images, increase the user's virtual experience, and scalability issues are the challenges faced by spatio-temporal data visualization[56],[57],[58]. Spatio-temporal data visualization will bring new experiences to humans.

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7. References
[1] Li DR, Ma J, Shao ZF. On Space-Time Big Data and Its Application[J]. Chinese Journal of Satellites, 2015(9):7-11.
[2] Bian FL, Du JY, Meng XL. Requirements,Applications and Challenges of Spatio-Temporal Big Data Processing[J]. Surveying and Mapping Geographic Information, 2016, 41(6):1
[3] Wang JY. Space-time big data and its application in smart cities[J]. Satellite Applications, 2017(3):10-17.
[4] Djuric N. Big data algorithms for visualization and supervised learning[J]. Dissertations & Theses - Gradworks, 2013.
[5] Ren Lei, Du Yi, Ma Shuai, et al. Review of Big Data Visual Analysis[J]. Chinese Journal of Software, 2014(9):1909-1936.

[6] Mei Xue. Exploration of Web Data Visualization in the Big Data Era[J]. Journal of Dajiang Magazine: Forum, 2013(8):14-14.

[7] Chen H. Research on the government information visualization in the era of big data[D]. Party School of CPC Jilin Province, 2017.

[8] Chen W, Guo F, Wang F Y. A Survey of Traffic Data Visualization[J]. IEEE Transactions on Intelligent Transportation Systems, 2015, 16(6):2970-2984.

[9] Olshannikova E, Ometov A, Koucheryavy Y, et al. Visualizing Big Data with augmented and virtual reality: challenges and research agenda[J]. Journal of Big Data, 2015, 2(1):22.

[10] Telea A C. Data Visualization: Principles and Practice[J]. 2014.

[11] Chen W, Sheng ZQ, Tao YB. Data visualization[M]. Beijing: Publishing House of Electronics Industry. 2013: 20-23 (in Chinese)

[12] Keim D, Andrienko G, Fekete J D. Visual Analytics: Definition, Process, and Challenges[C]/Information Visualization. Springer-Verlag, 2008:154-175.

[13] Chen M. Big Data Visualization Analysis[J]. Computer Education, 2015(5):94-97.

[14] Wünsche B. A Survey, Classification and Analysis of Perceptual Concepts and their Application for the Effective Visualisation of Complex Information[J]. 2004, 1(1):17-24.

[15] Card S K, Mackinlay J D. Readings in in - formation visualization: using vision to think Morgan Kaufmann Publishers Inc[J]. 1999.

[16] Liu J, Zhang W. Discussion on Patterns in Spatio-temporal Data Mining[J]. Modern Surveying and Mapping, 2017, 40(3): 31-34.

[17] Pei J, Han J, Mao R. CLOSET: An Efficient Algorithm for Mining Frequent Closed Itemsets[J]. Acm Sigmod Dmkt', 2000:21--30.

[18] Zikopoulos P, Eaton C. Understanding Big Data: Analytics for Enterprise Class Hadoop and Streaming Data[M]. McGraw-Hill Osborne Media, 1989.

[19] Keim D, Qu H, Ma K L. Big-Data Visualization[M]. IEEE Computer Society Press, 2013.

[20] Yuan XR. Big data visualization and visual analysis. 2013 (in Chinese). http://www.chinacloud.cn/upload/2013-12/13122814565172.pdf

[21] Oliveira M C F D, Levkowitz H. From Visual Data Exploration to Visual Data Mining: A Survey[J]. IEEE Transactions on Visualization & Computer Graphics, 2003, 9(3):378-394.

[22] Boyandin I, Bertini E, Bak P, et al. Flowstrates: An Approach for Visual Exploration of Temporal Origin-Destination Data[J]. Computer Graphics Forum, 2011, 30(3):971–980.

[23] Lu J. A Review of Big Data Visual Analysis Research[J]. Science Technology Prospect, 2015(16).

[24] Min Lu,2016. http://vis.pku.edu.cn/blog/author/min-lu/

[25] Zhu Q, Fu Xiao. The Review of Visual Analysis Methods of Multi-modal Spatio-temporal Big Data[J]. Acta Geodaetica et Cartographica Sinica, 2017, 46(10):1672-1677.

[26] Guo D, Zhu X, Jin H, et al. Discovering Spatial Patterns in Origin-Destination Mobility Data[J]. Transactions in GIS, 2012, 16(3):411-429.

[27] Balzer M, Deussen O, Lewerentz C. Voronoi treemaps for the visualization of software metrics.[M]// Dependable Computing - EDCC 5. Springer Berlin Heidelberg, 2005:20-37.

[28] Ren L. Research on interaction techniques in information visualization [Ph.D. Thesis]. Beijing: The Chinese Academy of Sciences,2009 (in Chinese with English abstract).

[29] Dai G, Chen W, Hong W, Liu S, Qu H, Yuan X, Zhang J, Zhang K. Information visualization and visual analytics: challenges and opportunities. Science China: Information Science, 2013,43(1):178-184.

[30] Liu XC, Cai XY, et al. Three Dimensional Visualization Analysis of Urban Road Traffic Operation Characteristics . Highway and Motor Transport [J]. 2018, 185:27-32.

[31] Friendly M, Denis D J. Milestones in the history of thematic cartography[J]. 2014.

[32] Arthur H. Robinson.http://www.datavis.ca/milestones/

[33] Research on Visualization of Web Data in the Era of Big Data.2017. http://www.thinkphp.cn/topic/51866.html

[34] Caicin Vislab.http://datanews.caixin.com/2015/tower/
[35] Kong X, Liu Y, Wang Y, et al. Investigating Public Facility Characteristics from a Spatial Interaction Perspective: A Case Study of Beijing Hospitals Using Taxi Data[J]. ISPRS International Journal of Geo-Information, 2017, 6(2):38.

[36] Fried D, Kobourov S G. Maps of Computer Science[C]// IEEE Pacific Visualization Symposium. IEEE Computer Society, 2014:113-120.

[37] Fowler J J, Johnson T, Simonetto P, et al. IMap: visualizing network activity over internet maps[C]// Eleventh Workshop on Visualization for Cyber Security. ACM, 2014:80-87.

[38] MIT SENSEable City Lab, 2017. http://senseable.mit.edu/

[39] Yang YC, Li L. Discussion on the Visualization Technology of Geographical Spatial Data in Smart Cities[J]. Bulletin of Surveying and Mapping, 2017(8): 110-112.

[40] Kong X, Liu Y, Wang Y, et al. Investigating Public Facility Characteristics from a Spatial Interaction Perspective: A Case Study of Beijing Hospitals Using Taxi Data[J]. ISPRS International Journal of Geo-Information, 2017, 6(2):38.

[41] Dai GZ, Tian F. Pen-Based User Interface. Press of USCT, 2009. 1-425 (in Chinese).

[42] Zhang X, Yuan XR. Treemap visualization[J]. Journal of Computer-Aided Design & Computer Graphics, 2012, 24(9):1113-1124 (in Chinese with English abstract).

[43] Ren L, Wang WX, Teng DX, et al. Nested Circular Fisheye Views for Visualization of Massive Level Information[J]. Journal of Computer-Aided Design & Computer Graphics, 2008, 20(3): 298-303.

[44] Keim D, Qu H, Ma K L. Big-Data Visualization[M]. IEEE Computer Society Press, 2013.

[45] Wong P C, Shen H W, Johnson C R, et al. The Top 10 Challenges in Extreme-Scale Visual Analytics[J]. IEEE Computer Graphics & Applications, 2012, 32(4):63.

[46] Chen C. An information-theoretic view of visual analytics[J]. IEEE Computer Graphics & Applications, 2008, 28(1):18.

[47] Chen M, Jänicke H. An information-theoretic framework for visualization[J]. IEEE Transactions on Visualization & Computer Graphics, 2010, 16(6):1206-1215.

[48] Daniel Weiskopf, 2017. http://openaccess.city.ac.uk/2855/1/Visual_Analytics_Methodology_for_Eye_Movement_Studies.pdf

[49] Dai G. Pen-based user interface[C]// The, International Conference on Computer Supported Cooperative Work in Design, 2004. Proceedings. IEEE, 2004:1-32-1-36 Vol.2.

[50] Walny J, Lee B, Johns P, et al. Understanding Pen and Touch Interaction for Data Exploration on Interactive Whiteboards[J]. IEEE Transactions on Visualization & Computer Graphics, 2012, 18(12):2779.

[51] Tominski C, Forsell C, Johansson J. Interaction Support for Visual Comparison Inspired by Natural Behavior[J]. IEEE Transactions on Visualization & Computer Graphics, 2012, 18(12):2719-2728.

[52] Isenberg P, Fisher D, Paul S A, et al. Co-Located Collaborative Visual Analytics around a Tabletop Display[J]. IEEE Transactions on Visualization & Computer Graphics, 2012, 18(5):689-702.

[53] Block F, Horn M S, Phillips B C, et al. The DeepTree Exhibit: Visualizing the Tree of Life to Facilitate Informal Learning[J]. IEEE Transactions on Visualization & Computer Graphics, 2012, 18(12):2789-2798.

[54] Lee B, Kazi R H, Smith G. SketchStory: Telling More Engaging Stories with Data through Freeform Sketching[J]. IEEE Transactions on Visualization & Computer Graphics, 2013, 19(12):2416-2425.

[55] Cui D, Guo XY, Chen W. Challenges and Latest Developments of Big Data Visualization[J]. Journal of Computer Applications, 2017, 37(7):2044-2049.

[56] Chen W. Big Data Visualization and Visual Analysis[J]. Finance & Electronics, 2015(11):62-65.

[57] karenfang, 2017. https://www.jianshu.com/p/1c0807dfff2a

[58] IEEE Pacific Visualization 2017. http://pacificvis.snu.ac.kr/