

Original Paper

Data Visualization Design: Strategies for Optimizing Information Delivery and Decision Support

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Abstract

This paper explores the fundamental concepts, methods, and principles of data visualization design. It provides a detailed analysis of key steps, such as data preprocessing, graphic design, interaction design, and multidimensional data visualization. The paper discusses how scientific design can enhance the readability and comprehensibility of data. Furthermore, it examines the role of data visualization as a crucial tool for information delivery and decision support in modern society, highlighting the importance of design principles such as simplicity, clarity, and consistency in improving data presentation. Finally, the paper looks ahead to the future development trends of data visualization design, particularly the application of augmented reality, virtual reality, and artificial intelligence technologies, which are expected to greatly advance the intelligence, personalization, and interactivity of data visualization.

Keywords

data visualization, interaction design, graphic design, data preprocessing, multidimensional data display

1. Introduction

With the advent of the information age, the rapid increase in data volume has made it increasingly difficult to extract valuable information from vast datasets. Data visualization, as a method of presenting data graphically, not only helps individuals identify underlying patterns and trends from complex data, but also facilitates the data analysis and decision-making process. Data visualization is more than just a simple presentation of data; it integrates elements of artistic design and emphasizes the depth and accuracy of information delivery. In fields such as business, policy analysis, and interdisciplinary communication, data visualization provides a more intuitive and interactive way to present data, significantly improving decision-making efficiency and accuracy.

2. Definition of Data Visualization

Data visualization is a method of converting complex, abstract data into easily understandable information through graphical representation. Its core approach utilizes visual forms such as charts, graphs, and maps to display the structure, patterns, trends, and relationships of data, thereby providing a clearer way to communicate information to the audience. This method not only helps individuals uncover hidden patterns in complex data but also facilitates data processing.

In the intersection of art design and data visualization, the presentation of data is not merely about information expression; it also requires consideration of how to convey the depth and accuracy of information through visual forms. Data visualization, as a means of information communication, emphasizes visual design and application elements. By carefully selecting and combining graphics, colors, layouts, and other elements, data visualization enhances the comprehensibility and interactivity of data. The goal is to break the traditional boundaries of textual and numerical expression, using graphical representations to make the underlying meaning of data more clearly communicated to the audience.

In addition to serving as an analytical tool, data visualization also plays a powerful role in decision support. In fields such as business decision-making and public policy analysis, data visualization helps relevant individuals quickly grasp key data, gain insights into potential trends and risks, and support a more efficient and accurate decision-making process. Furthermore, data visualization plays a crucial role in promoting interdisciplinary communication. It allows data analysis results to transcend academic disciplines, languages, and cultural barriers, providing a unified understanding platform for users from different backgrounds.

3. Methods of Data Visualization Design

3.1 Data Preprocessing

Data preprocessing plays a crucial role in data visualization design, as it directly affects the quality and accuracy of the data. Effective preprocessing not only improves the comparability and stability of the data but also enhances the scientific nature and expressiveness of the visual presentation. The first step in data preprocessing is data cleaning, which involves handling outliers, missing values, and duplicate data. Outlier identification and correction typically rely on statistical methods or interpolation techniques, aiming to eliminate disruptions to the overall structure of the dataset. Missing data can be managed either by removing incomplete records or applying interpolation methods to fill the gaps, ensuring the integrity of each data record. Removing duplicate data not only optimizes storage space but also ensures the accuracy of data analysis.

Data transformation is another critical step, which involves converting raw data into a format suitable for effective presentation and analysis. This process includes standardizing data types, such as converting textual data to numerical data or transforming date data into a consistent format. Additionally, normalization helps eliminate scale differences across different data dimensions, allowing for reasonable

comparisons and analyses of various data on the same scale, thereby enhancing the uniformity and precision of the visualization. Data transformation is not just a superficial adjustment; it aims to make data more intuitive and understandable when presented visually, enabling the audience to quickly recognize and comprehend the information.

Finally, feature engineering is also an essential aspect of data preprocessing. It involves extracting representative and highly relevant features from large datasets, further reducing the dimensionality of the data and improving the clarity and depth of the visualization. During this process, designers often create new feature dimensions through mathematical transformations or feature combinations, which better reveal the underlying relationships and patterns within the data. For large datasets, sampling techniques (such as random sampling or stratified sampling) can effectively reduce the complexity of data processing and accelerate the computational speed of visualization. Through these preprocessing techniques, the quality, reliability, and visualization effectiveness of the data are significantly enhanced, laying the foundation for subsequent analysis and presentation.

3.2 Graphic Design

In the graphic design phase of data visualization, the core task is to transform abstract data into intuitive and easy-to-understand graphical forms, enabling the audience to quickly capture and analyze complex data relationships. Choosing the appropriate type of chart is a crucial step in this process. Designers must consider the type, structure, and the message the data is meant to convey when selecting a chart. For example, bar charts are suitable for displaying comparisons of discrete data, line charts are ideal for showing trend changes, pie charts help display the proportion of parts to the whole, scatter plots demonstrate relationships between different variables, and radar charts are useful for presenting multidimensional data.

In addition to selecting the appropriate chart type, designers need to arrange the layout of the chart reasonably based on the data's dimensions and complexity, ensuring the chart has a clear, concise, and easily understandable structure. A key aspect of the design is avoiding information overload by properly organizing titles, axis labels, legends, and other elements to help users quickly capture the core information from the chart.

Moreover, the proper use of color and visual encoding in graphic design cannot be overlooked. Color not only serves to attract attention but also helps distinguish different datasets or emphasize specific information. In the design process, the chosen color scheme should balance both the aesthetic appeal and functionality of the chart. Designers often use vibrant colors to highlight important data and softer or grayscale tones for auxiliary information to avoid visual distractions. In terms of visual encoding, designers should skillfully use multiple channels, such as shape, size, color, and position, to visually represent relationships and patterns in the data. Different visual channels should be optimized according to data attributes and user cognitive patterns to enhance the readability and understanding of the data. In conclusion, through scientific graphic design, data can be effectively communicated, and users' analytical

capabilities can be enhanced, thus achieving the ultimate goal of data visualization: making information more transparent, easier to interpret, and facilitating decision-making.

3.3 Interaction Design

Interaction design in data visualization refers to the interaction between users and visual charts, allowing users to explore and understand data in greater depth. By enhancing user interaction with visual charts, data is transformed from a static presentation into a dynamic tool that can be explored and understood more thoroughly. Interaction design not only enhances the user experience but also effectively supports data analysis from multiple perspectives and levels. Common interaction design methods, such as hover effects, click interactions, and zoom functions, significantly increase the operability of charts. For example, dynamically displaying relevant data labels or detailed information when hovering the mouse allows users to gain deeper insights without interrupting the overall view. By clicking on specific elements within a chart, users can not only view more detailed data but also filter or select data according to their needs, enabling them to focus on subsets of data that are of interest. Zoom and pan functions offer users greater flexibility, especially when dealing with large datasets, allowing them to adjust the view and explore data trends in different regions.

Another key value of interaction design is in enhancing users' understanding and engagement with the data. Through linked chart designs, dynamic updates between multiple views help users intuitively recognize relationships between data points. For instance, when users make a selection or perform an operation in one chart, other related charts can be updated simultaneously, greatly improving the comprehensiveness and coherence of data analysis. Additionally, editable features enable users to customize charts based on their needs, further enhancing the flexibility and personalization of the visualization. These interaction design methods not only promote active user engagement but also provide personalized experiences, such as allowing users to adjust axes, modify chart types, or update charts in real time to adapt to dynamic data environments. By offering features like data export, interaction design also allows users to save and share analysis results, enabling the continued use of visualized data in multiple contexts. These rich interactive techniques not only improve users' ability to grasp and analyze data but also significantly enhance the practical value of data visualization.

3.4 Multidimensional Data Visualization

Multidimensional data visualization focuses on displaying and analyzing data with multiple dimensions or attributes. It helps users gain a more comprehensive understanding of the internal relationships and patterns within complex data structures through various graphical methods. Different types of graphic methods play an important role in visualizing multidimensional data, catering to different needs in data expression. For example, parallel coordinate plots are an effective tool for displaying relationships among multiple numerical variables using parallel axes, allowing users to intuitively identify trends and correlations between dimensions. Radar charts, on the other hand, present the values of different dimensions in a polygonal form, highlighting relative differences between dimensions, making them suitable for comparing the interactions among various attributes. The advantage of these charts lies in

their ability to concisely display both the differences and consistencies between multidimensional data, offering users a clear overall view.

In addition to parallel coordinate plots and radar charts, flat matrices, bubble charts, multidimensional scatter plots, and 3D charts are also common methods for visualizing multidimensional data. Flat matrices display different dimensions of data in a matrix format, with each dimension mapped to a row or column in the matrix. Visual encoding such as color or size is used to reflect the relationships between data, helping users quickly identify data distribution. Bubble charts represent multiple dimensions of information through bubble size, color, and position. This method not only shows the relative relationships between data but also reveals data distribution and trends. Multidimensional scatter plots map multiple dimensions to the positions and colors of data points, highlighting relationships between data points and facilitating the analysis of correlations between dimensions. 3D charts, as tools for visualizing three-dimensional or higher data, help users identify complex interactions and spatial distributions of three-dimensional data by presenting graphs in three-dimensional space.

Through these diverse visualization methods, designers can present rich, well-structured data information to users, allowing them to analyze and understand the underlying patterns and trends in multidimensional data more comprehensively and accurately.

4. Principles of Data Visualization Design

In data visualization design, adhering to a set of fundamental principles is key to ensuring that charts are not only visually appealing but also effectively communicate information. The principles of simplicity, clarity, consistency, readability, interactivity, and aesthetics work together to form the core framework for data visualization design. Simplicity emphasizes the removal of redundant elements to ensure that the chart presents only the most critical data, avoiding information overload. Consistency enhances the coherence and contrast of data interpretation by maintaining a unified design style. Meanwhile, readability and aesthetics improve the clarity and visual appeal of the chart through appropriate layout, color coordination, and visual balance. Interactivity gives users control over the data exploration process, adding depth and functionality to data visualization. The integration of these design principles optimizes the user experience and ensures the precision and efficiency of data communication, making data visualization not only a tool for display but also an important support platform for user analysis, understanding, and decision-making.

4.1 Simplicity Principle

The simplicity principle emphasizes the removal of unnecessary decorations and complex elements to ensure that the chart highlights the most critical data. By eliminating redundant information, designers can effectively reduce visual clutter, making the chart more intuitive and easy to read, thereby helping users quickly capture key data and trends. In addition, the clarity principle requires designers to ensure that elements such as titles, labels, and scales are sufficiently legible and distinguishable so that users can accurately interpret the information presented in the chart. Choosing appropriate fonts and color

combinations is crucial to achieving this goal. A clear, simple visual style not only prevents confusion during interpretation but also enhances the overall comprehensibility of the chart, improving the effectiveness of data communication. Simplicity and clarity complement each other, working together to optimize the user experience, ensuring that data visualization is not only visually appealing but also effectively conveys information.

4.2 Consistency Principle

The consistency principle requires that various elements of the chart, such as colors, shapes, and sizes, maintain a unified design style. This consistency helps users quickly identify similar information within the chart and promotes the relationships and contrasts between data, making the communication of chart content clearer and more intuitive. Additionally, the overall style and layout of the chart should remain consistent to ensure visual harmony and unity. Whether in the title, labels, or axes, designers should ensure that these elements are presented in a consistent manner throughout the chart, reducing the cognitive load on users when interpreting the data. Through this design approach, the consistency principle effectively enhances the readability and understandability of the chart, allowing complex data to be presented to users in a more unified and clear manner.

4.3 Readability Principle

The readability principle requires designers to choose appropriate chart types and layouts that match the characteristics of the data to ensure a clear structure and easy-to-understand information. To avoid overly complex or vague presentations, designers should simplify visual elements and optimize how data is presented, enabling viewers to quickly obtain key insights. Additionally, the size and proportions of the chart need to be appropriately controlled to ensure that the chart remains clear and readable across different display devices and resolutions. Whether viewed on desktop computers or mobile devices, the chart should adapt to varying viewing conditions to prevent issues such as being too small or proportionally distorted, which could affect the user's reading experience. By adhering to these design principles, the readability of the chart can be significantly improved, ensuring that data is communicated accurately and efficiently.

4.4 Interactivity Principle

The interactivity principle adds a dynamic and exploratory dimension to the data analysis process in data visualization design. By providing a variety of interactive features, designers enable users to engage actively with charts, allowing them to explore data more flexibly and uncover potential patterns and trends. Interactivity goes beyond simple visual presentation and transforms into an experience, where users can adjust the data view based on specific needs through various interactive operations such as clicking, hovering, filtering, and zooming, thereby revealing more layers of information. This interactive design not only enhances the user's sense of control over the data but also meets the diverse needs of users regarding the depth and breadth of data analysis, thus improving the functionality and adaptability of the data visualization. Users are no longer passive recipients of data but active participants in data exploration and analysis, greatly stimulating interest in and the depth of data discovery.

Effective interactive design requires the creation of a clear and intuitive interface that allows users to perform operations seamlessly, reducing the cognitive burden caused by interface complexity. Designers must ensure that interactive controls and features are user-friendly and that they follow a consistent design language and logical structure so that users, even when encountering the interface for the first time, can quickly understand and navigate the operations. An intuitive interface should not only facilitate ease of use but also include a feedback mechanism to ensure that users receive immediate and clear responses to their actions, further enhancing their sense of involvement and achievement in the data analysis process. By implementing such designs, the interactivity principle can increase user engagement and improve users' understanding and application of data, ultimately making data visualization not only a tool for information transmission but also a path for deep insights and decision support.

4.5 Aesthetics Principle

The aesthetics principle in data visualization design is not only about visual appeal but also a key factor in enhancing the effectiveness of data expression. Well-designed charts can effectively capture users' attention, and through the appropriate selection of visual elements such as color, shape, and layout, the aesthetic quality of the chart can be enhanced, thereby improving users' experience and understanding of the data. In this process, color combinations should not only align with visual harmony but also serve clear functional purposes, such as distinguishing data categories or highlighting key information, while avoiding excessive decoration that could cause visual fatigue. The design of shapes and layouts should focus on balance and symmetry to ensure visual harmony in the chart, avoiding the excessive clustering or disorder of elements. This approach helps users quickly capture the important information within the chart.

Although aesthetics is a subjective sensory experience, its impact on information transmission and user understanding is profound. By adhering to the aesthetics principle, designers can create visually pleasing charts that not only enhance the clarity and readability of the chart but also stimulate user interest and participation. Ultimately, this results in a perfect integration of data and visual design, enhancing both the transmission of information and the user's engagement with the content.

5. Future Development Trends of Data Visualization Design

With the rapid advancement of technology, the future of data visualization design is set to witness a series of innovations and transformations. The rise of augmented reality (AR) and virtual reality (VR) technologies indicates that the presentation of data visualization will no longer be limited to traditional two-dimensional charts and graphs. With the aid of AR/VR devices, users will be able to interact with data in a more intuitive and immersive manner within virtual environments, enhancing the depth and experience of data analysis. By dynamically displaying data in three-dimensional spaces, users can explore and manipulate the data in real time through gestures, voice commands, or other forms of interaction, discovering potential relationships and trends. The application of these technologies will not only break through the limitations of traditional data presentation but also create entirely new data

analysis scenarios, making complex datasets easier to understand and work with. Future visualization design will no longer be a one-way information output but will evolve into an interactive and dynamic analytical platform, enhancing user engagement and immersion.

At the same time, artificial intelligence (AI) and machine learning (ML) technologies will play an increasingly important role in the field of data visualization. With the support of intelligent algorithms, data visualization will not only enable automatic recognition of data patterns but also provide personalized analysis recommendations, helping users quickly uncover trends and anomalies within the data. For example, AI can automatically recommend the most appropriate chart types based on historical data and user preferences, even generating automated reports, greatly improving the efficiency and accuracy of data analysis. Additionally, by incorporating natural language processing (NLP) technology, users can generate corresponding charts and analysis reports simply by entering natural language commands, lowering the threshold for data analysis and making it easier for non-expert users to perform data analysis. This trend towards automation and intelligence will make data visualization more aligned with user needs, offering more personalized and flexible services. Moreover, as concerns about data privacy and security continue to grow, future data visualization design will place greater emphasis on data interpretability and transparency. Ensuring that users not only understand the meaning of data but also have clear explanations of data sources, processing methods, and analytical results will foster greater trust in the data. In conclusion, the future of data visualization will move towards smarter, more customized, and interactive approaches, becoming a powerful tool integrating advanced technologies and user needs, offering users richer, more accurate, and more convenient data analysis and decision-making support.

6. Conclusion

Data visualization design is not only the combination of technology and art but also an essential tool in modern data analysis and decision-making processes. Through scientifically sound evaluation, graphic design, interactive design, and multi-dimensional data presentation, data visualization not only aids users in understanding complex data and discovering underlying patterns but also facilitates efficient information transmission and decision-making support. With the development of technology, especially the real-world applications of augmented and virtual reality and artificial intelligence, the future of data visualization will exhibit smarter, more dynamic, and personalized trends. Future data visualization will break through the confines of traditional two-dimensional charts, offering more immersive and interactive user experiences, while also integrating intelligent algorithms and natural language processing, making data analysis more precise and accessible and opening the door to data exploration for non-professional users. As these new technologies continue to evolve, data visualization will gradually become a multifunctional platform for information transmission, decision support, and interdisciplinary communication, driving deep insights and decision-making across various fields.

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