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Review on Data Visualisation Techniques

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Abstract: The ascendancy of data visualization methodologies has rendered these instruments indispensable for contemporary decision-making processes within the epoch of exponential data proliferation. This review takes an in-depth look at various data visualisation techniques, providing an in-depth analysis of their applications, advantages and disadvantages. Data visualisation is an important tool for transforming large and complex datasets into intuitive graphical representations, enabling users to discover patterns, correlations and actionable insights more effectively. This review encompasses foundational visualization strategies including bar charts, line graphs, and scatter plots, in addition to sophisticated techniques such as heat maps, tree diagrams, and network diagrams, which are particularly efficacious for the representation of larger, more complex data sets. It also explores the growing importance of interactive visualisations, including dashboards and geospatial maps, which provide users with real-time data interaction and deeper exploration. In addition, emerging trends such as artificial intelligence, virtual reality and big data visualisation were seen as important advances that will shape the future of the field. Challenges such as data distortion, cognitive overload and accessibility issues were also analysed, highlighting the importance of choosing the appropriate technology based on the characteristics of the data, the user's task and the audience's needs to enable more effective communication and decision-making.

Keywords: Data visualisation, bar charts, line graphs, heatmaps, dashboards, network graphs.

1. Introduction

Data visualization has emerged as an essential instrument in the contemporary era of data-centric decision-making, converting raw data into graphical formats that elucidate patterns, trends, and inter relationships, thereby expediting insights extraction [1]. Amidst the proliferation of data across diverse sectors, the capacity to interpret and represent it effectively is paramount. Given the evolution of visualisation techniques, their application may lead to inefficiencies and ineffectiveness in expressing ideas if they are not properly understood, while challenges such as misrepresentation and accessibility issues in data visualisation remain daunting, suggesting the need for sustained research and development in related areas. This paper therefore explores different data visualisation techniques, their applications and the underlying theories that guide their effective use. Through a review of the literature, it elucidates the roles of traditional and modern visualization techniques across disciplines, discusses factors influencing tool selection, and surveys emerging trends and perspectives.

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2. Theoretical Framework of Data Visualization

Data visualization is rooted in cognitive psychology, human perception, and statistical reasoning. The Gestalt principles, initially developed in the early 20th century, remain fundamental in understanding how individuals perceive patterns, proximity, similarity, and continuity in visual information, according to the study done by Wagemans et al.[2]. The work of Cleveland and McGill in the area of graphical perception highlights how effectively humans can interpret different graphical elements, leading to the ranking of visualisation methods based on accuracy [3]. Their research demonstrated that some techniques, such as bar charts and line graphs, outperform others, like pie charts, in terms of perceptual accuracy. Lately, as the concept of data and information are introduced and prospering in the field of information technology, the concept of data visualisation becomes more technical with increasing occurrences in business purposes.

3. Common Visualization Techniques

Several techniques have been identified as being standard or common applications for data visualisation, each applicable to different types of data and analysis tasks. These are broadly classified into basic, advanced, and interactive visualizations.

3.1. Basic Visualization Techniques

Basic methods include bar charts, histograms, line graphs, pie charts, and scatter plots. Each of these visualisation tools has unique advantages in describing relationships, distributions and patterns in data. By understanding their specific applications, users can make informed decisions about which visualisation techniques to use for different analysis tasks. Table 1 provides a synopsis of these methods and their defining features.

Table 1: Basic data visualisation Attributes Summary

Technique	Representation	Common Use Case	Advantage
Bar Chart	Rectangular bars proportional to category value	Comparing categorical data	Quickly compares categories
Histogram	Distribution of continuous data over defined intervals	Visualizing data distribution for continuous data	Reveals patterns in data distribution
Line Graph	Data points connected by straight lines to show trends over time	Time-series analysis to observe growth or decline	Effective for showing trends over time
Pie Chart	Circle divided into sectors representing the overall scale	Presenting proportions in media and business	Simple for showing overall proportions
Scatter Plot	Individual data points plotted on Cartesian coordinate system	Exploring relationships, correlations, and outliers	Identifies correlations, clusters, and outliers

Bar charts and histograms are frequently employed in data visualization. Bar charts depict categorical data through rectilinear bars, with bar length corresponding to category value[4]. Histograms, conversely, illustrate the distribution of continuous data across specified intervals. These

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charts are simple but powerful because they allow the user to quickly compare categories or observe data distribution patterns. Line graphs are also widely used to describe trends over time. By connecting data points with straight lines, this technique allows for the visualisation of temporal patterns, such as growth or decline. Line plots are typically particularly useful in time-series analyses, where it is critical to understand how data change over time [3]. Pie charts, despite their widespread use, partition a circle into sectors proportional to the whole and have been criticized for their limited effectiveness in comparing category differences [5], with bar charts preferred for detailed analysis [3]. Scatter plots are used to visualise the relationship between two continuous variables by plotting individual data points on a Cartesian coordinate system. They are effective in identifying correlations, clusters, or outliers in data [4]. When coupled with additional variables or elements for instance colour or size, scatter plots can become more complex and informative, providing insights into multi-dimensional relationships.

3.2. Advanced Visualization Techniques

Advanced techniques often fulfil specific requirements depending on the characteristics of the data and the objectives of the analysis. Techniques such as heat maps, tree diagrams and network diagrams can visualise relationships, hierarchies and patterns that are difficult to recognise in numerical or textual formats. This table 2 below summarises the core attributes of heatmaps, tree maps, and network graphs, comparing their representation, common use cases, and advantages.

Table 2: Advance data visualisation Attributes Summary

Technique	**Representation**	**Common Use Case**	**Advantage**
Heatmap	Colour intensity indicates value magnitude	Biology (e.g., genomics for gene expression levels)	Quickly highlights variations in data magnitude
Tree Map	Nested rectangles represent hierarchical data with size proportional to value	Business, Finance, IT (e.g., website usage, budget allocation)	Effectively visualizes large datasets with hierarchical structures
Network Graph	Nodes represent entities, edges represent relationships between entities	Social network analysis, biology, telecommunications (e.g., large-scale system interactions)	Ideal for visualizing complex relationships and large-scale networks

Heatmaps, tree maps, and network graphs represent sophisticated visualization strategies for complex data sets. Heatmaps utilize color intensity to depict data values within matrices, with applications spanning genomics to illustrate gene expression levels [6]. Heatmaps are commonly used in fields like biology, particularly in genomics, to show the expression levels of thousands of genes simultaneously. Tree maps are used to represent hierarchical data in a nested format. Each rectangle in the tree map represents a category, with its size proportional to a quantitative value [7]. Tree maps are particularly effective in visualising large amounts of data, making them popular in areas such as business, finance, and information technology for analysing complex structures, like website usage or budget allocations. Network graphs are used to represent relationships between entities. They consist of nodes (representing entities) and edges (representing connections). Network graphs, comprising nodes and edges, delineate entity relationships and are instrumental in fields like social network analysis and biology for illustrating systemic interactions [8], particularly in large-scale networks like the internet or ecosystems.

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3.3. Interactive Visualisation Techniques

Differing from the previous two classifications, interactive visualisations allow the user to interact with the data visualisation in real time, dynamically exploring and analysing the information provided by the visualisation. Interactive methods not only enable data tools to present data in multiple dimensions with complex relationships, but also encourage user actively engage with data instead of consuming information in a passive way. Dashboards serve as interactive platforms showcasing concurrent data visualizations, permitting users to filter, drill down, and customize views, thereby enhancing decision-making in business intelligence through real-time KPI monitoring [9]. Geospatial visualizations merge geographic data with visual representations, facilitating mapping and spatial analysis. Choropleth maps, for instance, are applied in public health and urban planning, as noted by Nykiforuk and Flaman (2009) and Li et al. (2021), often incorporating interactivity for layered data exploration [10][11].

4. Factors Influencing the Choice of Visualisation Technique

The effectiveness of data visualisation techniques is shaped by a number of factors, including the type of data, the analysis task and the target audience. Understanding these factors is fundamental to choosing the appropriate visualisation approach. Data self is always the first consideration in term of its type and complexity in its structure, regards the tool we use. Different visualisation techniques are suited for different types of data. For instance, categorical data is best represented using bar charts, while continuous data can be visualised with line graphs or histograms [3]. Complex, multi-dimensional data may require advanced techniques, such as parallel coordinates or 3D scatter plots, to reveal patterns that are not immediately apparent in simpler visualisations. Audience expertise dictates the complexity of visualizations, with simpler forms like bar and line graphs suited for general audiences [5]. However, audience expertise dictates the complexity of visualizations, with simpler forms like bar and line graphs suited for general audiences [5], and more sophisticated ones like network graphs or heatmaps for experts. The visualization's purpose, whether exploratory or communicative, also determines the choice of technique, with interactivity being key for exploratory tasks [1] and clarity for conveying findings.

5. Emerging Trends in Data Visualization

Recent advances in technology and data science have led to the development of new visualisation techniques and platforms, expanding the possibilities for data representation. Technological and data science innovations have spurred the creation of novel visualization techniques and platforms, broadening the scope of data representation. With the growing influence of machine learning, data visualisation is evolving to include AI-driven insights. Techniques such as auto-generated visualisations, where algorithms identify and present key patterns in the data, are becoming more prevalent [12]. AI also enriches interactivity by anticipating user queries and delivering real-time contextual data. These technologies allow users to navigate through multi-dimensional data in ways that traditional 2D visualisations cannot. For instance, in VR, users can walk through a 3D scatter plot or interact with a dynamic network graph, leading to new forms of data analysis and storytelling [13]. As datasets grow larger, visualising big data has become a significant challenge. Techniques such as streamgraphs and parallel coordinates are designed to handle the complexity and volume of big data [4]. Additionally, cloud-based platforms now enable scalable visualisations that can handle millions of data points while maintaining interactivity and responsiveness.

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6. Challenges and Limitations in Data Visualization

Despite the benefits, data visualization faces challenges. Misrepresentation due to poor design, such as misleading scales or color usage, can result in erroneous interpretations [14].In addition, the cognitive load of complex visualisations may be overwhelming for users, especially for those with limited expertise in data interpretation. Another limiting factor is the accessibility of data visualisations. For example, colour-blind people may struggle with certain colour schemes, while less digitally literate users may find interactive dashboards difficult to navigate. Ensuring that visualisations are both accurate and easy to use for different audiences is a key issue for data scientists and designers [15].

7. Conclusion

Data visualisation is an important tool for transforming raw data into actionable insights and comprehensible information. Through a range of techniques, from simple bar charts to complex network diagrams and immersive virtual reality experiences, data visualisation enables individuals and organisations to understand and communicate data effectively. The choice of visualisation technique depends on factors such as data type, complexity and audience, with each approach having its own unique strengths and limitations. Rising technologies such as Artificial Intelligence, Virtual Reality and Big Data platforms are pushing the boundaries of data visualisation, making it more interactive, scalable and insightful. Nonetheless, challenges such as misrepresentation, cognitive burden, and accessibility necessitate meticulous design and ethical reflection. As the significance and volume of data escalate, proficiency in the art and science of data visualization is imperative for future data valorization by individuals and organizations. The present analysis delineates the features of various data visualization tools, considerations for their selection, and examines emergent trends and constraints, offering a synthesis of the field. The narrative is predominantly theoretical and literature-driven, with sparse practical illustrations. To enhance comprehension, a more granular examination through specific exemplars and case studies is advocated. However, access to high-quality case studies on data visualisation is limited because data visualisation is a technology that is supported across a wide range of industries and each domain may employ unique techniques, making it difficult to find directly relevant and comparable case studies. To mitigate these limitations, future inquiries should extend beyond tool-centric analyses to incorporate user perspectives, which are pivotal in assessing user-oriented technologies. Insight into user expectations, interpretations, and applications of visualization tools will facilitate the development of more nuanced evaluation frameworks.

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