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Literature Review on the Development of Visualization Studies (2012–2022) †

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Abstract: In the past decade, the visualization and transformation of data and information have attracted lots of research interest, while visualization has gradually extended to all industries. Based on the retrieval of core literature in a Web of Science search from 2012 to 2022, this study finds that these developments mainly discussed the change of visualization and its related concepts, current research hotspots, and influential journal papers. Consequently, it aims to explore research gaps and provide directional guidance for future research.

Keywords: data and information visualization; visualized analysis; literature review; visualization studies

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1. Introduction

1.1. Research Background

Most industry and business data are newly evaluated with the rapid development of the 'Internet +' in recent years. Big data technology extracts relevant information from a large number of unstructured or multi-structured datasets. As the McKinsey Global Research Institute (MGI) released in their report '*Big Data: The next frontier for Innovation, competition, and productivity*', the development of big data has been observed as the foreword and future trend of contemporary academic development. The process of forming images of objects through visual observation is a sort of mental processing procedure. Visualization improves people's ability to observe things and the formation of the overall concept for them. It displays data or information from different dimensions in graphical ways and promotes decision-makers or stakeholders to quickly and effectively understand the data or information.

Whether it is data visualization or information visualization, it has gradually been put on the frontier of research in this century and has developed prosperously in the past decade. In the vigorous development of big data analysis, InfoVis has been widely used in various data analysis applications. There are many published articles relating to big data analysis, which involves many researchers in diverse disciplines [1–3]. Data visualization has become the premise as an effective method of research and decision making.

1.2. Purpose and Significance

The study selected 'core' articles published from 2012 to 2021 and classified them. The main contents were categorized according to the following aspects. The first is the development of visualization-related concepts and the relationship between them: what are the directions for the evolution of visualization-related concepts based on these concepts? Secondly, according to the collection of the related literature, the specific result of the research influence of visualization technology over the past decade is described with the current research trends. These research results provide directional guidance for subsequent researchers and explore the research gap between studies and applications.

2. Methods and Steps

Literature research based on the retrieval system of the Web of Science (web of knowledge.com (accessed on 1 March 2023)) allows the effective retrieval of the following keywords: 'data visualization' and 'information visualization'. Web of Science is a well-known database that is most commonly used to retrieve literature [4,5]. The information is selected by evaluation of readers, and its credibility and influence are favored by scholars. The content covers journals, books, reports, seminars, and other academic information. It also includes three influential databases, such as Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (A & HCI). According to the retrieval of the keywords 'data visualization' and 'information visualization', these two are combined for analysis on the basis of the research objectives.

3. Analysis and Discovery

3.1. Development and Transformation of Visualization-Related Concepts

The development of visualization-related concepts changes over time, and these related concepts are evolving constantly where a contextual relationship is created. The essence is the visual interaction with computers. The conceptual change is mainly reflected in the development of visualization from 'technical implementation' to 'consideration of the recipient's cognition', and from scientific research suitability for professionals to mass communication. Visualization is gradually broadening the field of such influence.

Starting from several terms including data, information, data visualization, scientific visualization, information visualization, and knowledge visualization, the paper sorts out the relationship and common characteristics between different concepts and perceptions.

In information generation, the concept of data has been changed over a long history. Before the appearance of pictographs, people used ropes to record events, and later, stone walls were used. Such records are the essence and an original way for information delivery and representation. By the 10th century AD, people recorded the positions and changes of celestial bodies at different times with simple geometric figures and coordinate concepts together with longitude and latitude [6]. Nowadays, data means digital data [7] collected from various sources and composed of symbols and facts that are discrete and unexplained. When it has nothing to do with other data, it may have no meaning [8]. Information is data that has been interpreted or processed, and therefore contains certain meanings [9]. Usually, information tends to spread more visually than data.

The definition of data visualization is related to a set of techniques designed to extract relevant information from a large amount of unstructured or multi-structured data [10]. It usually refers to the data extraction method and belongs to the technical category. With the continuous evolution of the concept of data visualization, people are accepting new concepts with both scientific visualization as well as information visualization. With the impact of modern computer technology, the connotation of data visualization has been greatly expanded from scientific computing visualization to information visualization and knowledge visualization. Thus, the related research objects include spatial or non-spatial data and human knowledge [11]. As a result, the scope of data visualization is expanded.

Scientific visualization was proposed first in 1987. It refers to the use of computer graphics and image processing to create visual images, replace large and complex digital presentation forms, and help people better understand the concepts of science, technology, and results. Scientific visualization is a further extension of data visualization, which extends the real sensibility of graphic images [12], and its purpose is to help people better understand the meaning of data. Scientific methods are enriched by focusing on guiding data sets and seeing invisible information [13]. Therefore, scientific visualization is more inclined to reveal the information of data in specific application disciplines for professional researchers. Complex geographic data, measurement data, and scientific data are obtained in a process with computers. Re-analysis and combination sometimes need three-dimensional space with light source rendering to understand the real effect, which is regarded as three-dimensional real-world visualization. From the perspective of conceptual development, variants and sub-types based on data and scientific visualization (cartographic visualization) or knowledge domain (statistical visualization) are also created [12].

Information visualization (usually referred to as InfoViz) is one of the tools to allow and/or improve big data analysis. The prosperity of big data analysis has led the related technology to the wide application of information visualization in various fields from finance to sports and politics [10]. Its research and development started in the 1990s and began as a disciplined development. The purpose was to help users explore, understand, and analyze data through progressive, iterative visual exploration [14]. By using computer graphics and interaction to help mankind solve problems [15], and mimicking human's five senses, an immediate understanding of information helps researchers explore and understand deeper information and meanings [1–3]. Therefore, information visualization becomes important in applying abstracted data with interactive visual interfaces for various purposes [16]. Information visualization is closely related to the user's cognition as it pays more attention to people's acceptance, which is more associated with psychology, visual design, and human-computer interaction in addition to computer graphics for business methods. Information visualization is more inclined to visual communication than scientific visualization.

The development of knowledge visualization was carried out in this century. In the working document '*Knowledge Visualization-Towards a New Discipline and its Fields of Application compile*' by Eppler and Burkhard, knowledge visualization is considered to be a milestone and a new research category. Knowledge visualization stresses guiding the spread of knowledge among the public more than information visualization, and it expands the scope of viewing objects by sharing [17]. Knowledge visualization was developed based on information visualization and scientific visualization, and uses visual description to promote the transmission of group knowledge and creative creation. The purpose is to study the use of visual expression to improve knowledge transfer and creation among people [18]. Knowledge visualization is applied to represent knowledge in a visual format. It aims to support cognitive processes; to generate, represent, and build retrieval sharing; and to use knowledge [19]. Based on the above concepts, the difference between various visualization concepts is mainly reflected in the evolution of the definition of visualization over time and their relationships. There are also common features between concepts that are an interactive visualization of data (Figure 1).

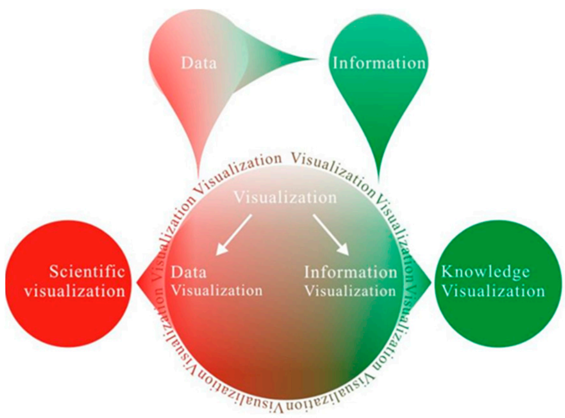

Figure 1. Development of concepts.

3.2. Influence of Visualization Research

This study explores the influence of visualization in three aspects: the influence of research, the influence of journals, and the influence of co-citation. The influence of research largely depends on the time for the development of the discipline and the number of people involved in the research. The influence of journals is not only related to the number of published articles but also depends on the depth and breadth of the research and a universal value. The influence of co-citation is based on professionalism [19]. The impact of journals is judged by the number of publications to prove the journal's attention on data visualization and information visualization.

In line with the retrieval of keywords of 'data visualization' and 'information visualization' and the core attributes, a total of 2229 research articles are merged, and then the top 10 articles published in 853 journals are selected.

The journals in descending order are as follows.

IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, 110 published, BIOINFORMATICS, 92 published, COMPUTER GRAPHICS FORUM, 53 published, BMC BIOINFORMATICS, 48 published, IEEE COMPUTER GRAPHICS AND APPLICATIONS, 34 published, PLOS ONE, 32 published. IEEE ACCESS, 30 published, ISPRS INTERNATIONAL JOURNAL OF GEO-INFORMATION, 29 published, JOURNAL OF VISUALIZATION, 27 published, NUCLEIC ACIDS RESEARCH, 25 published.

To a certain extent, the number of publications is not proportional to the impact factor, and the impact factor is not completely dependent on the number of publications but on the rate of their citations. However, the abuse of impact factor has affected the influence of journals [19]. The quality of publication does not depend on the journal impact factor. The impact factor alone does not evaluate the quality of journals precisely. Hence, the impact factor of a journal has an asymmetric relationship with the impact of journals, as shown (Tables 1 and 2).

Table 1. Journal influence.

Rank	Journal	Quantity
1	IEEE T VIS COMPUT GR	110
2	BIOINFORMATICS	92
3	COMPUTER GRAPHICS FORUM	53
4	BMC BIOINFORMATICS	48
5	IEEE COMPUT GRAPH	34
6	PLOS ONE	32
7	IEEE ACCESS	30
8	ISPRS INT J GEO-INF	29
9	JOURNAL OF VISUALIZATION	27
10	NUCLEIC ACIDS RESEARCH	25

Table 2. Impact factor (2022).

Rank	Journals	Impact Factor
1	NUCLEIC ACIDS RESEARCH	16.971
2	BIOINFORMATICS	6.937
3	IEEE T VIS COMPUT GR	4.597
4	IEEE ACCESS	3.367
5	PLOS ONE	3.240
6	BMC BIOINFORMATICS	3.169
7	ISPRS INT J GEO-INF	2.899
8	IEEE COMPUT GRAPH	2.088
9	COMPUTER GRAPHICS FORUM	2.078
10	JOURNAL OF VISUALIZATION	1.331

In terms of co-citation of articles in data visualization and information visualization, the top 10 co-cited articles comprehensively show the change in the content of professional fields. For example, the D-3 methods mentioned in the data-driven article are not for building a single framework but for providing an efficient operation of data-based documents. This shows that proprietary representation and extraordinary flexibility are necessary for analyzing the visualization [20]. For example, as a tool for the unification of biology, gene ontology mentioned in articles promotes the transformation of the concept of the naming system on the premise of a unified understanding of biology and its interoperability [21].

There is a high degree of correlation between co-cited articles to be manifested in the frequently referred articles of a particular field. For example, in the study of the top 10 journals, 'Empirical Studies in Information Visualization: Seven Scenarios', 'VisDesigner: Expressive Interactive Design of Information Visualizations', and 'D-3: data-driven documents' are influential in information visualization with high frequencies of citation (Table 3).

Table 3. TOP10 co-citation literature distribution based on keywords 'data visualization' and 'information visualization'.

Rank	Title	Cited Times
1	D-3:Data-Driven Documents	84
2	Raphical perception-theory, experimentation, and application to the development of graphical methods	35
3	A multi-level typology of abstract visualization tasks	28
4	Low-level components of analytic activity in information visualization	27
5	Readings in Information visualization: using vision to think	26
6	Protovis: agraphical toolkit for visualization	23
7	Gene ontology: tool for the unification of biology	22
8	The eyes have it: a task by data type taxonomy for information visualizations	22
9	viSNE enables visualization of high dimensional single-cell data and reveals phenotypic heterogeneity of leukemia	17
10	An integrated encyclopedia of DNA elements in the human genome	17

In addition to the citation rate, researchers' academic influence can also be defined based on the number of their publications. First of all, a limited number of researchers concentrate on a certain field. For example, Lee, B. published 34 articles from 2012 to 2021, of which 14 were selected through core screening. Collaborations among influential researchers with him are also found (Table 4).

Table 4. TOP 10 influential researchers ranked by keywords 'data visualization' and 'information visualization'.

Rank	Author	Times	Percentage
1	Ma, Kwan-Liu	9	0.09%
2	Olovira, OsvaldoN, Jr	9	0.09%
3	Chen, Min	8	0.08%
4	Isenberg, Petra	8	0.08%
5	Yuan, xiaoru	8	0.08%
6	Chen, Wei	7	0.07%
7	Jamroz, Dariusz	7	0.07%
8	Lee, Bongshin	7	0.07%
9	Paulovich, Fernado V	7	0.07%
10	Qu, Huamin	7	0.07%

3.3. Research Trends and Imbalances

The overall trend is based on the retrieval of keywords. The research trend is observed in two aspects: (i) the number of published articles each year and the overall trend, and

(ii) the analysis of popular research areas. From 2012 to 2021, the overall trend showed an upward increase with the total number of articles increasing year by year, among which data visualization contributed greatly. The research imbalance is mainly reflected in the ratio of articles that have been highly cited. The research on data visualization has gradually increased, and the total number of articles has increased from 138 in 2012 to 306 in 2021. Over the 10 years, data visualization has become the focus of research. However, the research on information visualization has fluctuated and become stable. The total number of articles is 299. The average is 29.9 articles per year, with the largest number of 46 in 2019 and the least of 16 in 2015 (Figure 2).

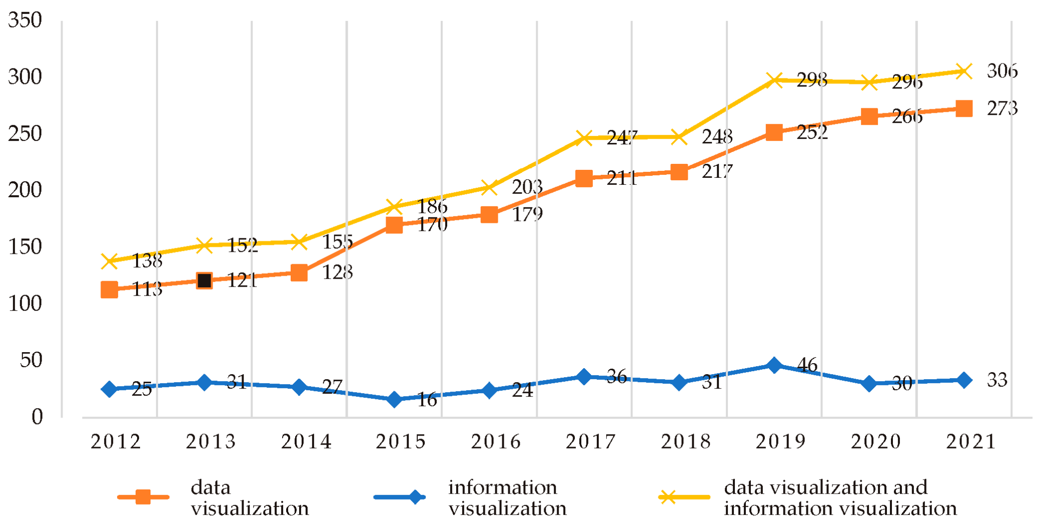

Figure 2. Publication trends of keyword retrieval ('data visualization' and 'information visualization').

The paper retrieves keywords within the research field of these articles, calculates them according to the frequency of occurrence, and then eliminates similar keywords by using cluster analysis. The top 10 applicable research fields are then selected in terms of wide applications, particularly in biology, geography, safety, health, commerce, transportation, energy, and personal applications. In the screening and sorting of keywords, it is found that data visualization and information visualization belong to the category of computer science. Most of the related research is about human-computer interaction and the realization of technology. The main research on visualization is mainly related to computer science. However, bio-related disciplines, biotechnology, biochemistry, biological information, and other applications have gained popularity in the past decade. With the wide application and rapid increase of computing power, the visualization of multi-faceted scientific data is becoming more important than before in engineering, medicine, or climate research (Table 5).

Table 5. Research field distribution based on keywords 'data visualization' and 'information visualization'.

Rank	Research Fields	Quantity	Percentage
1	Computer science	893	40.06%
2	Engineering	366	16.41%
3	Biochemistry molecular biology	294	13.18%
4	Mathematical computational biology	195	8.74%
5	Biotechnology applied microbiology	174	7.80%
6	Chemistry	165	7.40%
7	Mathematics	162	7.26%
8	Science technology other topics	111	4.97%
9	Environment sciences ecology	93	4.17%
10	Medical informatics	77	3.45%

From a trend analysis, the imbalance of research is found in two different aspects. First, the number of articles is different. Among 2229 retrieved articles, 1930 articles (86.6%) deal with data visualization, while 299 articles (13.4%) deal with information visualization. The number of articles on data visualization is 6.74 times higher than that on information visualization (Table 6).

Table 6. Proportion of the number of articles and researchers in the combined retrieval based on keywords 'data visualization' and 'information visualization'.

Keywords	Numbers of Researchers	Percentage
Data visualization	7915	87.6%
Information visualization	1120	12.4%
Data visualization and information visualization	9035	100%

Data visualization requires a large amount of unstructured or multi-structured data compared to information visualization [10]. Data visualization was coined in the 1950s with the advent of computer graphics [22]. Information visualization was introduced in 1999. The development of data visualization needs a longer time and is more mature than information visualization. Due to the required time for development, data visualization needs more research than information visualization. Thus, among 9035 researchers, 7915 (87.6%) are related to data visualization, while 1120 (12.4%) are related to information visualization. The ratio of the researchers for each research area on the visualization is similar to that for articles.

There is a significant difference in the number of highly cited articles. The top 10 articles have a citation rate of more than 500, and the citation rate of the top three articles is higher than 1000 times (Table 7).

Table 7. Information related to TOP10 articles retrieved by 'data visualization and information visualization'.

Rank	Title	Cited Times
1	Integrative Genomics Viewer (IGV): high-performance genomics data visualization and exploration	4098
2	qgraph: Network Visualizations of Relationships in Psychometric Data	1130
3	GGTREE: an R package for visualization and annotation of phylogenetic trees with their covariates and other associated data	1095
4	viSNE enables visualization of high dimensional single-cell data andreveals phenotypic heterogeneity of leukemia	968
5	Mantid-Data analysis and visualization package for neutron scattering and mu SR experiments	871
6	Pathview: an R/Bioconductor package for pathway-based data integration and visualization	698
7	ETE 3: Reconstruction, Analysis, and Visualization of Phylogenomic Data	669
8	Anvi'o: an advanced analysis and visualization platformfor 'omics data	594
9	Protter: interactive protein feature visualization and integration with experimental proteomic data	586
10	Artemis: an integrated platform for visualization and analysis of high-throughput sequence-based experimental data	565

The research goals of highly cited articles are diverse. When an article is cited by others at a certain time, the article generates attention for its research outcome [23]. For example, the article 'Integrative Genomics Viewer (IGV): high-performance genomics data visualization and exploration' is cited 4098 times. Its research outcome allows a wide range of applications and provides a basis for other research.

4. Conclusions

Based on the keywords of 'data visualization' and 'information visualization', this study finds the development and transformation of concepts, the influence of research, the trend, and the imbalance of research.

4.1. Concept Development and Its Transformation

The concept of data visualization has evolved continuously, covering scientific visualization and information visualization. Scientific visualization is a further extension of data visualization to the real perceptual image. Information visualization is more inclined toward visual communication than scientific visualization, and knowledge visualization is more inclined toward guiding knowledge among the public than information visualization that expands the scope of the viewing object with the characteristics of sharing.

In conceptual transformation, visualization is more influential on the application of scientific research from professionals to mass communication. For example, knowledge visualization promotes visual information that only professionals can present as an explanation that the public understands.

4.2. Research Influence

This article mainly describes and analyzes three bases, namely, the influence of journals, the influence of researchers, and the influence of co-citation articles. In terms of the influence of journals, more influential journals are concentrated in software engineering and biologically related fields, but the relationship between the number of published journals and the impact factor is not proportional. In the aspect of co-citation, the analysis result of co-citation articles shows that the top 10 co-cited articles have high versatility and a high degree of correlation between co-cited articles. This correlation in a particular field implies frequent citations or widely cited topics.

4.3. Research Trends and Imbalance

The research trend is analyzed in two aspects: the number of published articles each year and the overall trend. The total amount of articles is increasing year by year, especially the research on data visualization, but the research on information visualization fluctuates less and becomes stable. This also reflects the imbalance of research. The imbalance is reflected in the analysis of popular research areas that are widely distributed, including biological disciplines, biotechnology, biochemistry, biological information, and other applications. In other fields, engineering and climate research are becoming more important.

5. Research Limitations and Prospects

The result of data visualization and information visualization provides researchers with preliminary insights into their research direction. The paper only employs the Web of Science core database, so the overall number of topics collected from the literature may be relatively biased. Thus, future research needs more literature retrieval pipelines such as Scopus, CSCD, and KCI to obtain comprehensive information. In terms of the objectives, this study is descriptive and mainly discusses the related characterizations. Subsequent research is necessary to explain more about the profound connotation and reasons for the presented results in this study and to conduct a summary analysis.

There are various methods such as cluster analysis [24] and semi-structured interviews [25,26] that are applicable for implementing the related research. Recent studies have focused on empirical methods and applications. With empirical methods, more information research is deployed to the application [27] to know in the practical field.

In the future, the research on visualization will become popular regardless of the number of researchers and articles in development. As a consequence, research on information visualization is still in great need. The reason is that information visualization is mainly for understanding characteristics of multidisciplinary cross-cutting nature, and it is difficult to carry out related research on cognitive science and visual design. These two disciplines have great differences, so the integration of the two disciplines is not easy. In addition to this, the concepts of information visualization reflect the popular trend of visualization technology, though, at present, it does not have much demand.

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