A Review of Recent Trends and Issues in Visualization

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Abstract—Visualization is an extensive and diverse area of research which is a combination of various distinct but overlapping areas. The term visualization came into history late but idea of expressing something using graphical means is prevalent from many past centuries. Due to the invention of computer graphics and animation, the interactivity has been added in visualization in modern digital era. The visualization nowadays is not only limited to generating visual scenes but the analysts are emphasizing to analyze their data using automated analysis combined with interactive visualization for effectively analysing, perceiving, interpreting and decision making. This paper presents the survey of work done by various prominent authors in the field of visualization. The objectives, advantages, disadvantages of visualization are also covered. The researchers are facing various difficulties in data/information visualization. The degree of challenges in visualization depends upon various factors such as size, complexity, quality, diversity and utility of data/information. The challenges faced by authors in different fields of visualization are also detailed.

Keywords-Visualization; Digital Forensics; Network Security; Data Mining; Knowledge Management, Risk Management, Uncertainity; Qualitative Data;

I. INTRODUCTION

There is long tradition of expressing something using visualization in history. Computers are not only the means of generating visualization rather other technologies are also used for the said purpose. The evidence of different visuals and techniques are available from many past centuries. Visual aid in the form of expression, gesture, signal, visual symbol, map, painting, chart, poster, slide, sign etc. all are the ways of visual communication. Visual communications come in myriad forms and various such means used for visual communication in past are discussed by Tversky[22]. Depending upon the necessity and availability of technology, the various paintings and images on different material such as walls, monuments, papers etc. all are the examples of visualization. It is true that the term visualization came quite late in history but the idea of expressing something through graphical means is prevalent from many past centuries.

In modern era, the visualization is carried in every field. The kinds of tools and techniques used depend upon application to application. Due to increase in computer's processing efficiency, graphics generation capability and storage capacity, the use of visualization in various computer application domains such as engineering, science and technology, commerce, business , medicine, education & training etc. is routine matter.

II. VISUALIZATION HISTORY- A GLANCE

The representation of city of Babylon found in the region of Kirkuk, Iraque is oldest map which was carved in stone about 6200 b.c.[12]. Similarly, the maps that express some quantities visually by location and aerial extent engraved in stone by precocious Chinese cartographers [2] in 12th century. Tufte[2] has cited many pictures from past centuries that shows maps and aerial photographs. Author also detailed the strategies used for their design. Tukey[13] invented various graphics displays such as box plots, stem-leaf plots, two-way table displays, hanging root grams etc. for data analysis. Tufte[1] has cited many images from past centuries that gives the representation of mechanism & motion, of causes & effects, of process & dynamics and of explanation and narration. Michael [11] has made wide study on history of data visualization from medieval to modern era. Michael [11-12] has divided visualization history into eight periods and these are: Early maps & diagrams(Till 17th Century), Measurement & Theory (1600-1699), New graphic forms (1700-1799), Begin modern period(1800-1849), Golden age(1850-1900), Modern dark Ages (1900-1949), Re-birth(1950-1974) and High-D Vis(1975-2005).

Visualization in recent context is created using computer graphics. Ben Laposky[14] in 1950 created first graphics image through Oscilloscope. William Fetter [14-15] first time used term computer graphics to describe his graphic design. Human faces (Herman Chernoff 1973) were used to represent multi-dimensional data which were arranged as rows and columns and features of each face such as length of nose and curvature of mouth etc. are used as components of data [16]. Marc 1985[20] proposed points as universal meta-primitives for geometric modeling and rendering applications for 3D geometry. Herman [17] displayed human organs based on data obtained from x-ray photographs of internal structure of body. Baecker [18] in 1981 produced a computer generated video to demonstrate the sorting techniques.

Levoy et al [19] explored volume rendering techniques to display of surfaces from sampled scalar functions. The modern visualization started with the evolution of computer graphics and majority of work on modern visualization has been carried after 1987 by especially introducing a new topic of computer graphics on visualization in scientific computing [21].

III. UNDERSTANDING VISUALIZATION

Visualization is a process of transforming data or information to visuals by applying filters and rendering techniques on it. The idea behind visualization is to give graphical representation to complex data using which user can better understand complicated problems easily. Actually, visualization techniques present complex data in concise and precise manner in visual form in less time that can be very helpful to users to deal with their domain specific problems. Using visualization one can know the hidden truth about the information in hand to draw conclusion and take better decision. Visualization helps to create, refine, and use a mental model for problem space understanding [67]. The information visualization can be used for explanation, exploration and expression [138].

A. Objectives of Visualization

The various objectives of visualization are [5,6,8]:

a) It acts as an aid to user to understand and analyze data.

b) It helps the decision makers to easily draw conclusion from complicated data and makes decision rapidly.

c) It is insight means it helps in grasping the inward or hidden nature of problem in hand.

d) It presents information efficiently in visual form in simple and clear manner.

e) One can recognize and recall visuals rapidly rather than numeric and textual information. It reduces the time taken to process and understand the problem through visual representation. It also minimizes the surface area for viewers to apply the skepticism filter.

f) It allows users to explore, analyze and present large amount of data rapidly.

g) It is helpful in understanding the relationship between different entities under study.

In order to make visualization more effective, it is important to understand the human perceptual system. Presenting data/information in visual form does not guarantee that it will be useful[7]. Visualization is only useful if it is properly used and can be harmful when it is poorly used. Bresciani et al [93] studied various perils of risk visualization and classified visualization disadvantage into cognitive, emotional and social. The authors detailed all the three categories of disadvantages according to designer or users perspective.

B. Limitations of Visualization

The major limitations of visualization are:

i). The visualization may be ambiguous, confused, unclear, inaccurate, misleading and inconsistent due to data duplicacy, over simplification, logic used, labels & colors used for presentations that is difficult to interpret.

ii). The visualization may be de-focused, hiding, implicit and uneven due to technical, logical and functional developments and constraints that fails to give clear meaning that is desired.

*iii).*The visualization may be redundant, computationally complex, overloaded due to complex, voluminous, multidimensional, multi-valued, heterogeneous and multi-source data that fails to give real-time and interactive results.

iv). The visualization may not be universally acceptable due to non-availability of standard visual format i.e. symbols, labels, colors and scripts etc. used for visualization and diverse problem domain.

v). The users and developers of visualization tools require various types of knowledge and expertise such as technical, insight, interactive visualization, problem understanding and domain. The lack of knowledge in developing and using visualization tools not only produce wrong inference but may be fatal for taking certain strategic decision.

IV. GENERAL VISUALIZATION PROCESS

Entire visualization process is divided into various steps. The number of steps used depends upon the kind of techniques used in visualization. In general, there are five steps for visualization and these are: Acquisition, Filtering, Mapping, Rendering and Visualization. The various steps are given in Figure 1:

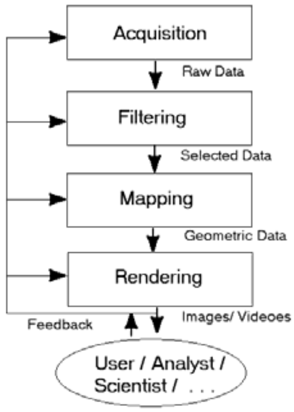

Figure 1. General steps in visualization process.

Data acquisition is the preliminary step in visualization. This is data about the problem or object under consideration for study or investigation. Depending upon the requirement data is acquired from the source by applying proper device such as sensor, simulator etc. The data may be acquired manually depending upon the need. The data so acquired is stored in a file for further processing.

Data filtering is used to extract the portion of data to be visualized. Filtering is used to reduce the bulk data to a data of interest (DOI) for visuals. Filtering the based data using some simulation methods into another form is more informative and perhaps less voluminous [10]. Filtering is an important step and selecting wrong DOI means taking wrong data for visualization. This step may prove to be fatal in those applications where decisions are to be made purely on the basis of visuals and decision maker may take wrong decision. The commonly used filtering techniques are cropping, re-sampling, segmentation, clustering, slicing etc.

Data Mapping is used to transform selected data into graphical primitives. The graphical primitives are geometric primitives such as lines, triangles, polygons, glyphs etc. and have attributes in the form of color, texture, opacity etc.

Rendering step is used to bring realism in images. In case of 3D images, there may be complex surface having number of polygons. It is essential to identify which surface is visible from current viewpoint. In addition each surface must not have same color. The various visible surfaces may appear shaded depending on the amount light they receive from light source. Rendering is complex as well as time consuming.

The analysts, scientists, engineers etc. go through the images on screen and take decision on the basis of the images. The data is properly visualized if visualization is effective, accurate, efficient, aesthetic and adaptable [9]. Visuals can be interactively changed with the help of proper feedback at each stage.

V. Recent Trends in Visualization

The term visualization is treated as generating visual scenes with the use of suitable technology. Due to the invention of computer graphics and animation, the interactivity has been added in visualization in modern digital era. The majority of task on such techniques has been done in past 2-3 decades only. The purpose of visualization is to insight that has many characters such as complex, deep, qualitative, unexpected and relevant [6]. The visualization nowadays is not only limited to generating visual scenes but the analysts are emphasizing to analyze their data using automated analysis, an approach based on data mining and machine learning, combined with interactive visualization for effectively analysing, perceiving, interpreting and decision making. Research for developing software for visualization has boomed from past a few decades. Initially, data visualization was designed manually but with the evolution of digital computer, computer graphics and soft skills, now a days, it is designed using software. Using this approach: 1) It is easy to revise or restore the visualization with supplementary or latest data, 2) It is user friendly, 3) It can be used to understand multi-dimensional or heterogeneous data, 4). It is easy to generate visuals for a small chunk of data from vast.

A. Visualization in Digital Forensics

Digital forensic is a process in which scientifically proven techniques are used to collect, preserve, analyze and present evidence from digital sources for investigation purpose that is used to defend or prosecute the criminals in court. Due to the evolution of digital technology various digital devices have been used for acquisition, processing, storing and dissemination of information such as computer, mobile phone, digital camera, storage media, communication devices etc. and are source of digital information. The Internet itself is bigger source of digital data. The above mentioned devices may have digital evidence in the form of login history, documents, e-mail records, browser history and other digital record. The main purpose of investigator is to collect accurate information for as the evidences. The various above mentioned sources are generating large amount of data daily. It is very difficult to extract required accurate data from large amount of data for investigation and as well as for further decision making.

Visual representation of digital data is helpful in extracting required evidence from large volume of data. Viewers can process visually represented log records in fraction of time as compared to log file itself [42]. Lowman [23] developed, Webscavator, a software tool to visualize web history that is helpful in analyzing browser records. Meng et al[28] developed a forensic analysis system, visualize association inside emails (VAlE) that helps the investigators to gather the clues and evidences during investigation using visualization. Vlastos [31] developed a storage media related tools to visualize digital evidence in 3D data mode. Leschke et al [30] developed a customizable data exploration Tool, Change-Link, where investigators can see visual representations of directories that have changed over time within a computer operating system that supports the Microsoft volume shadow copy service (VSS). Tioh[33], proposed a tool to take advantage of the information contained within volume snapshot service (VSS) by applying the fisheye focus and context visualization approach to the directory tree structure. The tool presents a sequence of individual boxes for each to represent change-over-time for each directory/file. Fei[34-35], proposed a Self-Organizing Map Forensic Analysis (SOMFA) tool for clustering, visualizing and analyzing forensics data. With Forensic Tool Kit(FTK)-5[27], developed by Access Data, investigators can view data in multiple display formats, including timeline, cluster graphs, pie charts and more. Olsson[24] created a prototype, Cyber Forensic TimeLab(CFTL) , tool that scans a disk image for timestamps and then visualizes them on a graphical timeline. This makes it easy for the viewer to see the various contents such as e-mail messages, IM conversations and web browser history on the same timeline. Baum [25] developed a visualization tool to analyze malwares, to discover specific behavior patterns, obtained from memory images of Windows XP and attempted to identify types of malwares. Chavhan[36] gives review and survey of visualization techniques for digital forensic. The information visualization using explore, investigate, and correlate (EPIC) process model helps in reducing the size of evidence, helps in identifying the items of probable value, and helps in restructuring the evidence and setting up relationship between them[40-41]. Haggerty [140] presents E-mail Extraction Tool (EET) that is helpful for displaying the client-based e-mails and exploring the social networks.

*B. **Visualization in Network Security***

Network Forensics is analysis of data collected from active computer network traffic to assist with intrusion detection, auditing and monitoring [43]. The major sources of data to visualize network security are log files auto created using some application software, operating system, antivirus software, browser and utilities installed on the system. The data contained inside network packets can be scanned and used to create visualization. The intrusion detection systems (IDS) uses user defined rules that monitors log files and /or network packets to detect security breach. Goodall[143] gives various applications of network security visualization. CyberViz[44], a visualization tool for network forensics analysis using an Intrusion Detection System. Abdullah [45] proposed a network traffic visualization technique that is helpful to the administrators in recognizing the attacks on computer through port. The author proposed view of port statics on the basis of which IDS alerts are issued. Peng et al [47] presented intrusion detection and visualization system that exploits the signature based anomaly detection techniques. Nurbol[48] presented a real-time intrusion detection security visualization framework where users can interact with attack scene-element and real-time rearrangement based on planner scheduling.

Zhang [60] proposed DDoSViewer for interactively detecting and visualizing DDoS attacks through the analysis of visual patterns. Chang et al[54] propose security quad and cube (SQC), an efficient method for analyzing network security through visualization that monitors anomalies occurring in an entire network and displays detailed information of the attacks. Fuchs et al[144] proposed, BANKSAFE, a scalable and web-based visualization system that analyzes health monitoring, firewall and IDS logs. Zhou[55] proposed , NetSeeRadar, for network security awareness based on multisource logs. The proposed system is able to monitor network and view overall security situation using radial graph. Streilein et al [56] proposed Panemoto, a passive network monitoring tool that provides both ‘at-a-glance’ displays and drill-down analysis capability. Chen et al [57] proposed to visualize security situation in real time. The proposed technique predicts attack path, recognize attack intention and estimate the impact through analysis of attack graph that helps the administrator to approach intrusion steps, determine security status and assess threat. Karapistoli et al[46] reviews various network security visualization tools for wireless sensor network. Authors also detailed the various challenges in visualization of wireless sensor network. Ferebee [50] has presented a survey on security visualization and Elhenawy [49] has presented a survey on using visualization techniques for intrusion detection. Kasemsri [51] surveyed various network security visualization techniques. Authors analyzed various techniques from the data models, visual primitives, security analysis tasks, etc. point of view. Shiravi[52] gives a comprehensive review of network security visualization and broadly classified all security visualization research work till 2012. Zhang[58] gives a survey on visualization designs for computer network security. Author organized various security visual analytics into five categories. Etoty [59] surveyed and evaluated the capabilities of existing visualization tools used for anomaly based intrusion detection that meets analyst’s needs. Liu et al[32] classify the network traffic into four layers and compared the network traffic visualization tools available for each layer. The Network Visualizer (TNV) is used represent network data movement based on packet capture (pcap) technique [141]. Best et al [142] details various challenges in visualization of cyber network defense as: lots of data, lots of data source, data sources not linked, data quality, cadence of network, progression of threat progression, and balancing risk and rewards.

C. Visualization in Data Mining

With the evolution of digital computer and Internet technology, a large volume of data is being generated daily. The data so generated may be multidimensional and complex. It can be fruitful for humanity if it is explored and analyzed, rather than dumped, and make its proper use. Though computer has high computational power but its displaying capability is limited. Visual data mining is a technique of exploring and analyzing large volume of data with combined efforts of machine and human brain. A major difference between visual data exploration and data mining is that the former is human guided process and later is automatic process. Both are used for extracting useful information for decision making. It is advantageous to use Visual data exploration as compared to automatic data mining techniques due to the fact that [61,64]:1) It deal with highly inhomogeneous and noisy data, 2) It is intuitive and requires no understanding of complex mathematical or statistical algorithms or parameters and 3) It can provide a qualitative overview of the data, allowing data phenomena to be isolated for further quantitative analysis. Keim[62] classified various visual data exploration techniques into different categories as: geometric projection, pixel-oriented, icon based, hierarchical, graph-based, and hybrid. Ankerst[65] classified visual data mining techniques into three categories: 1) visualization techniques independent of data mining algorithms, 2) Visualize results from mining algorithms, and 3) Visualization of intermediate results of mining algorithms. VDM do not support an iterative and comprehensive sense making process [66]. Madhavarapu et al [69] categorizes Visual Data Mining approaches into three categories: 1) Data Mining process visualization. 2) Data Mining result visualization 3) Interactive Visual Data Mining.

D. Visualizing Knowledge

Knowledge is an intangible asset of an individual or an organization. Knowledge visualization (KV) examines the visual representation used to develop the transfer and creation of knowledge between at-least two persons [73,75]. KV aims to transfer insight, experiences, attitudes, values, expectations, perspectives, opinions and predictions [74]. The knowledge visualization is used to sustain the practice of creating and sharing knowledge with others [147]. The knowledge visualization framework developed by Burkhard [75] has four component types *i.e.* function, knowledge, recipient and visualization. The framework includes the perspectives of both users and tools. Burkhard et al [77] discuses a Tube Map Visualization application used to communicate long term projects. Burkhard et al [78] compares the effectiveness of the Project Tube Map and the Gantt Chart for inter-functional communication in large projects and concluded that the Project Tube Map is useful for (1) drawing attention and keeping interest, (2) presenting overview and detail, (3) visualizing who is collaborating with whom, (4) motivating people to participate in the project, and (5) increasing recall. X. Bai et al [79] proposed a flexible knowledge visualization system, contextual adaptive visualization environment (CAVE), a context-sensitive and adaptive platform. Medeni et al [76] proposed a knowledge visualization model to identify success rates of the online news agencies and online newspapers regarding how consistent they are with the concluded actual news content. Lee et al [80] applied various knowledge visualization techniques- factor analysis, pathfinder network and context-based ontology, to present research results by clustering scientific papers taken from the ISI web (CiteSeer papers) and suggested its use for ubiquitous computing. A similar study is conducted by Lee et al[81] for knowledge management visualization. Humphrey et al [82] developed and used knowledge visualization tools based on decision trees for machine learning. Heide et al [83] proposed a combined approach of dynamic knowledge mapping, which is based on a manual creation of the underlying context of the visualization. Knowledge visualization is extensively applied in intelligence applications to enhance cognition, facilitate perception and inquiries, and decision making.

Visualization in Knowledge Management: Duffy[71] defines knowledge management as a process that drives innovation by capitalizing on organizational intellect and experience. The different authors have defined knowledge management in different ways. More than 100 definitions authored by prominent scholars of KM have been detailed by J. P. Girard [72]. Eppler et al [84] explored the potential of visualization for corporate knowledge management. Authors adopted visualization arrangement embedded in a conceptual framework to guide the visualization application in knowledge management keeping in view the type of knowledge that is visualized. Authors finally summarised that how knowledge visualization formats can be used to facilitate knowledge transfer, creation, identification, evaluation, and application in knowledge management. Biloslavo et al [85] conducted a study on the various visualization tools used by managers and entrepreneurs for decision making process in Slovenia. Authors studied the role of visualization tool for improving the process of transmitting the ideas, assumptions and information within organization. The study shows the importance of visualization as a facilitator of ideas and knowledge transfer. Fang et al [86] introduced knowledge visualization technology to manage high valued and rich knowledge in Deep Web knowledge management. The authors perceive that knowledge visualization can be used to transform the hidden knowledge to visible knowledge and, create knowledge. Pinaud et al [87] developed Atanor, a knowledge management system, whose graphical model for visualizing knowledge is tree-based and showed its advantage. More than 10 visualization tools used for knowledge management are discussed [88].

E. Visualization in Risk Management

Hubbard[89] defines risk management as the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events. Risk visualization designates the systematic effort of using (interactive) images to enhance the quality of risk communication along the entire risk management cycle[95]. Visual displays (graphics) have desirable properties that can enhance the understanding of (numerical) risk and possess at least three desirable properties for communicating risk [96]: a) the graphics reveal data patterns that may go undetected otherwise; b) specific graph types may evoke automatically specific mathematical operations and c) unlike numbers, graphs can attract and hold people's attention because they display information in concrete, visual terms. Eppler et al [90] examines how visualization can be applied to risk management by reviewing current approaches. A conceptual framework is proposed to illustrate the use of visualization in risk management with several application examples. Visualization techniques can be used very effectively in public risk communication.

Visualization tools can be used to actively participate the users to explore the given risk data and utilize it for interactive visualization [91]. Authors also discussed various pros and cons of risk visualization. Chandra et al [92] suggested a risk visualization model based on adaptive learning. Sharif et al [97] provides a summary of software risk assessment tools (visualized as well) along with their strength and weaknesses. Kontio et al [98], in their study work, concluded that a well organized visualization approach can be helpful for capturing more risk information than less formal methods. Hosmer [99] proposes icons and visual conventions to rapidly grasp and present information security (INFOSEC) attack scenarios. Authors perceive that visualization helps in identify missing threats, steps, and safeguards by making potential attack scenarios intelligible to a large number of people.

Hettig et al [100] presented a pilot study that tested the efficacy of visualizing Android app permissions using, for example, actual private photos, the current location and text messages sent in near past. The authors view is that their visualization system made users more aware of possible risks arising due to the installation of smartphone apps. The users currently show limited awareness of threats and risks during the selection and installation of a new app. Due to which the safety of their personal data is at stake. The situation can be improved by emphasizing the risks associated with an app's installation. Gresh [101] presented a survey on the history and science of the risk visualization from a variety of perspectives. A survey of the results in medical and health care domain which has received significant attention in terms of communicating risks associated with conditions, treatments, and side effects are also presented. Author investigated visual communication of risk through the representation of its mathematical estimation.

F. Uncertainty Visualization

Business dictionary defines uncertainty as a situation where the current state of knowledge is such that (1) the order or nature of things is unknown, (2) the consequences, extent, or magnitude of circumstances, conditions, or events is unpredictable, and (3) credible probabilities to possible outcomes cannot be assigned [103]. Uncertainty visualization deals with uncertain data from simulations or sampled data, uncertainty due to the mathematical processes operating on the data, and uncertainty in the visual representation [104]. Pang et al[105] places the uncertainty visualization methods into various categories as: add glyph, add geometry, modify geometry, modify attributes, animation, sonification (not visual), and psycho visual. Thomas et al [106] designed an in-depth typology for visualizing uncertainty. One component of their category of rationale-based tasks was to expose uncertainty. Sanyal et al [107] evaluates the perception of uncertainty in one-dimensional and two dimensional data among four categories *i.e*. error bars, scaled size of glyphs, color-mapping on glyphs, and color mapping of uncertainty on the data surface. Zuk et al [108] describes the use of perceptual and cognitive theories for the study of different uncertainty visualizations *i.e*. vector field, molecular structure, archaeological reconstructions, 2D stochastic simulation, grid-based annotation lines, particle movement, air traffic flow decision Support and Surfaces. Authors theoretically detailed the strengths and weaknesses of different aspects of the visualizations.

Zuk et al [110] analyzes the support of uncertainty visualization in cognitive and meta-cognitive processes. Leaving uncertainty out of data visualization promotes assumptions that lead to more uncertainty in the reasoning process and the viewer may not be aware of this uncertainty. Providing cues about uncertainty in representation may promote consideration of other representations and help further the exploration[110]. Collins et al [113] visualization technique reveals the uncertainty and variability inborn in statistically-derived lattice. Authors cited various case studies using hybrid layout with varying transparency, colour, and size to reveal the lattice structure that expose the inherent uncertainty in statistical processing. MacEachren et al [114] provide detail insights on how to signify different categories of uncertainty. Their experimental design integrates theory from Visual Semiotics, Cartography, Information Visualization, and Visual Perception. The experiments examine relative effectiveness of a set of uncertainty representation solutions when used to represent three types of uncertainty (due to accuracy, precision, and trustworthiness) matched to three components of information (space, time, and attribute). Jiao [115] proposes a technique, for uncertainty analysis and uncertainty visualization based on fiber orientation distribution function (ODF) glyphs, associated with high angular resolution diffusion imaging (HARDI). Authors conducted their study on synthetic data and HARDI human-brain data. Hermosilla et al [116] present a set of techniques that for easy visualization of the uncertainty in the fiber data sets and provide a better understanding on the visualization of brain fibers by means different visual cues such as textures, silhouettes, ambient occlusion, and animation.

Skeels et al [117] reviewed various uncertainty techniques within a number of domains and empirically evaluated. Authors believe that by designing visualizations, there is need to better understand that how users view uncertainty and how it is currently represented. By developing a way to make the uncertainty associated with data more visible, one can help users better understand, use, and communicate their data.

Lapinski [118] developed a systematic approach to express uncertainty i.e. Uncertainty Visualization Development Strategy (UVDS having eleven steps that helps in understanding data as well as uncertainty. Authors applied UVDS for uncertainty visualization of the Canadian Recognized Maritime Picture (RMP). Pang [119] provides an overview of some visualization practices and techniques that incorporate data uncertainty in the presentations. Author also studied that how visualization and uncertainty play a role in two natural hazards applications i.e. Seismic and weather. In case of natural hazards adding uncertainty, especially in the form of multi-values, can be quite challenging from the visualization point of view. Furthermore, multidimensional multivariate multi-valued data sets are inherently much larger and hence present a computational and informatics challenge in itself. MacEachren et al [120] identified key challenges being faced by researchers in visualizing information uncertainty to support analysis and decision making. Geo-statistical literature show three types of uncertainty in cancer mortality and incidence maps[111] *i.e.* local, spatial and response. Author studied representation of local and spatial uncertainty by three dimensional displays.

G. Qualitative Data Visualization

Data that approximates or characterizes but does not measure the attributes, characteristics, properties, etc., of a thing or phenomenon is called as qualitative data[103]. Simply, the data having no numerical value is called as qualitative. It is descriptive and not easy to analyze. The focus groups, interviews, open-ended questionnaires, observations, on-line data etc. are the examples of qualitative data. Eppler et al [123] presented a systematic overview of the formats available for describing classifications visually. Authors distinguish among four types of visual classifications based on their ability to express relationship and these are compilations, configurations, layers, and trees. Henderson et al [125] reviews various techniques for visualizing qualitative data and suggested a variety of new ways such as data word clouds, tree representations and spectrum displays that evaluator may use to describe their data. The suggested techniques that can be used to evaluate various stages: planning and design, analysis, and reporting. Erwin [127] proposes two approaches to manage the data sprawl and data sameness generated by online qualitative research. In first case, it used visual coding strategies to reduce the visual plane of the data and create a more compact, visually differentiated analytic environment. In second case, it defined a class of analytical tools that can permit “data poking”—fast, simple and visual meta explorations of data that can suggest and frame more robust analytic strategies at the ground level.

Slone [126] perceives that there is no qualitative analysis tool that has the analytic power, visual effectiveness, and Universality of quantitative tools like pie charts, bar charts, and scatter plots. Author suggested to merge qualitative information with the human ability to derive understanding from graphics. Mennis et al [128] studied the theoretical principles of combining qualitative and quantitative data and methodologies within the context of geographic information systems (GIS). The aim of the study is to develop and demonstrate the principles of cartographic visualization for exploring qualitative activity space data. Knigge et al [129] studied that how grounded theory and visualization might be used together to construct an integrated analysis strategy that is both iterative and reflexive, both contextual and conceptual. Verdinelli et al [130] review the data visualization methods used by three prestigious qualitative research journals within 2006-2009. The study was concentrated on types of display, the frequency of use and the purpose of visual display.

VI. Challenges and Issues in Visualization

The visualization is created to analyze and explore information at different point of view to disclose hidden information treasure for better understanding and decision making. The first and apparent challenge is posed by voluminous information. Extracting desire information from bulk data is tedious task. Moreover, the visualization process leads to loss of information. Nevertheless, the losses may be intentional or unintentional [134]. To minimize the loss of information is tedious task. The choice of a visualization technique used always depends upon the information context. Developing visualization tools require various type of knowledge such as technical, insight, interactive visualization, problem understanding and domain. Choosing a suitable visualization for a particular domain among the available is challenging task. It is very difficult to maintain real time interactivity when dealing with larger numbers of items. In addition, the universal usability remains a formidable challenge [132]. To visualize data various visualization techniques are used. Creating meaning of geometric or structural patterns with the help of visualization elements that can convey the users their meaning effectively is challenging task [134]. In case of qualitative data, introducing structure, to identify patterns and outliers, without oversimplifying or misrepresenting it and without losing the subtle meaning or emotions rooted in it is a challenging task [125]. Liu et al [133] predicts five challenges in information visualization as: usability, scalability, heterogeneous data analysis, In-Situ visualization, and errors and uncertainty. Chen et al[137] details unsolved problems in visualization as: usability, domain specific knowledge, education, intrinsic quality measure, scalability, aesthetic, causality and visual inference. Laramee et al [136] coarsely classified visualization problems in three categories: Human Centred, Technical and Financial.

The data one need to visualize may be linear, planner, volumetric, temporal, multi-dimensional, hierarchical and network. Visualizing three dimensional vector data sets is a challenging problem and this challenge is further aggravated if additional dimensionality is added to the data sets [138]. The main challenge is how to get reliable visualization from high-dimensional data sets? As far as visualization of network data is concerned, visualization systems attempt to represent network flow, topology, and geography in a single image. This is challenging because displaying a large number of connections with lines results in visual clutter. The high-dimensional, time-varying and dynamic nature of sensor data, the unpredictable network behavior, and the error-prone transmissions and operations, all are source of challenges in wireless sensor network visualization [46].

Childs et al [139] discussed various challenges related to visualization software. Authors discussed various issues belonging to six categories i.e. parallelization, processor architectures, application architecture and data management, data models, rendering, and interaction. Visualization allows more data to be presented as compared to text but designing an interactive visualization system that makes the information of interest visually apparent is someone tedious.

Some challenges for knowledge management visualization has been studied by Ahlers et al[26]. The knowledge management is used to promote the flow and development of information and knowledge. The purpose of visualization is to impart that knowledge to user through appropriate interface. The associations between goals of the knowledge and user interface design is quite complex that poses a challenge in a developing mechanisms for the structuring, navigation, retrieval and Visualization of knowledge [26]. The decisional problem context, a base for knowledge visualization, may have different factors such as problem situation, physical surroundings, time, knowledge visualization tasks, etc. Hence, the knowledge visualization context is complex and dynamic in nature that causes problem in developing effective knowledge visualization [79].

As far as uncertainty visualization is concerned, the various visualization systems are lack of comparison techniques for finding differences and errors between two 3D visualizations. To address inherent difficulties in defining, characterizing, and controlling comparisons among different data sets is tedious task. In addition, the corresponding error and uncertainty in the experimental, simulation, and/or visualization processes is a challenging task[150]. Moreover, the datasets where multiple, contradictory measurements seems to provide too much data also offers challenge for uncertainty visualization. In addition uncertainty of a measurement, simulation or product provides an additional data stream which is generates further challenge [104]. Visualizing multidimensional, multivariate, multi-valued data into 2D space is quite challenging since several dimensions need to be mapped [119,122]. While visualizing uncertainty, the probability distribution such as mean, standard deviation etc. is used to summarize uncertainty. Perceptually efficient encoding of appropriate summary statistics of the data is a challenging task [102]. The some studied carried along with challenges in each area of visualization are given in Table 1.

TABLE I. VISUALIZATION APPLICATIONS, SURVEYS, REVIEWS, STUDIES, TOOLS, CHALLENGES AND ISSUES.

	Scope & Glimpses of Visualization Research	**Challenges/Problems/Issues**
Visualization inDigital Forensics	✓To collect, preserve, analyze and present evidence from digital sources for investigation purpose. ✓Lowman [23] Webscavator - a software tool to visualize web history.Meng [28] VAlE - a forensic analysis system to visualize association inside emails. Leschke [30],Vlastos [31], Tioh[33] developed tools. Fei[34-35], SOMFA - a Self-Organizing Map Forensic Analysis tool for clustering, visualizing and analyzing forensics data. FTK-5 - Forensic Tool Kit to view data in multiple display formats, including timeline, cluster graphs, pie charts etc.[27]. Olsson[24] CFTL - Cyber Forensic TimeLab, a tool that scans a disk image for timestamps and then visualizes them on a graphical timeline. ✓Osborne [40-41] Explore, investigate, and correlate (EPIC) process model.Haggerty [140] presents E-mail Extraction Tool (EET)	✓ e-mail related investigation may involve more than one computer. ✓ Voluminous data must be analyzed within stipulated temporal limitations. ✓ Data Anomalies: point, contextual and collective.

Visualization in Network Security	✓To analyze data collected from active computer network traffic to assist with intrusion detection, auditing and monitoring. ✓Karapistoli [46], Elhenawy [49], Ferebee [50], Shiravi [52], Zhang [58], Etoty [59] reviews/surveys the security or network visualization. ✓Abeyrathne[44] CyberViz - visualization tool for network forensics analysis using an Intrusion Detection System. ✓WAIDS[152] - web application intrusion detection system for detecting input validation attacks based on web application parameters having identical structures and values. Zhang[60] DDoSViewer - a visual interactive system for detecting DDoS attacks through the analysis of visual patterns. Chang[54] SQC - Security quad and cube, an efficient method for analyzing network security through visualization that monitors anomalies occurring in an entire network and displays detailed information of the attacks ✓Fuchs[144] BANKSAFE, a scalable and web-based visualization system. Zhou[55] NetSeeRadar – a system for network security awareness based on multisource logs. Streilein[56] Panemoto - a passive network monitoring tool that provides both 'at-a-glance' displays and drill-down analysis capability ✓Tnv - Time-based Network Analyzer[141].	✓ Heterogeneous, multidimensional, and multisource. ✓ Lots of data, lots of data source, data sources not linked, data quality, cadence of network, progression of threat progression, and balancing risk and rewards[142]. ✓ The high-dimensional, time-varying and dynamic nature of sensor data, the unpredictable network behavior, and the error-prone transmissions and operations for wireless sensor network visualization [46]. ✓ Scalability and time-efficient visualization.
Visualization in Data Mining	✓technique of exploring and analyzing large volume of data and identifying useful patterns. Keim[61,64] gives advantageous to use Visual data exploration as compared to automatic data mining techniques.Keim[62] classified visual data exploration techniques into six categories : geometric projection, pixel-oriented, icon based, hierarchical, graph-based, and hybrid. Ankerst[65] classified visual data mining techniques into three categories: Visualization techniques independent of data mining algorithms, Visualize results from mining algorithms, and Visualization of intermediate results of mining algorithms. Madhavarapu[69] categorizes Visual Data Mining approaches into three categories: Data Mining process visualization, Data Mining result visualization and Interactive Visual Data Mining.	✓ Heterogeneous, multidimensional, and multisource. ✓ Scalability, dynamic data stream, quality of data problem, user acceptability [146].
Visualizing Knowledge/ Knowledge Management	presentation to improve the transfer insight, experiences, udes, values, expectations, perspectives, opinions and predictions. ✓Burkhard[75,77,78] Tube Map Visualization application used to communicate long term projects and compares its effectiveness. ✓Bai[79] CAVE - contextual adaptive visualization environment ,a context-sensitive and adaptive platform. Medeni[76] proposed a knowledge visualization model to identify success rates of the online news agencies and online newspapers. Lee[80,81] applied three knowledge visualization techniques- factor analysis, pathfinder network and context-based ontology. Humphrey[82] developed and used knowledge visualization tools based on decision trees for machine learning. Heide et al [83] proposed a combined approach of dynamic knowledge mapping.	✓ Developing mechanisms for the structuring, navigation, retrieval and Visualization of knowledge[26]. ✓ Complex and dynamic nature of knowledge visualization context[79]
Visualization in Risk Management	✓To identify, assess and prioritize risks to minimize, monitor, and control the probability and/or impact of unfortunate events. ✓Eppler et al [90] examines how visualization can be applied to risk management. Chandra[92] proposed a model of risk visualization for adaptive learning.	

	Sharif[97] provides a summary of software risk assessment tools (visualized as well) along with their strength and weaknesses. Kontio[98] concluded that a defined and sufficiently expressive visualization approach can help capture more of the risk information than less formal methods. Hosmer[99] proposes icons and visual conventions for rapid comprehension and presentation of information security (INFOSEC) attack scenarios.	
Uncertainty Visualization	✓Deals with uncertain data from simulations or sampled data, uncertainty due to the mathematical processes operating on the data, and uncertainty in the visual representation. ✓Skeels [117] reviewed various uncertainty techniques. ✓Lapinski [118] UVDS - Uncertainty Visualization Development Strategy, a systematic approach to express uncertainty that helps in understanding of both the data and the uncertainty. ✓Pang[105,119] Categorises uncertainty visualization methods and provides an overview of some visualization practices and techniques that incorporate data uncertainty in the presentations. ✓MacEachren [120] identified key challenges being faced by researchers in visualizing information uncertainty. ✓Thomas et al [106] designed an in-depth typology for visualizing uncertainty. ✓Sanyal et al [107] evaluates the perception of uncertainty in one-dimensional and two dimensional data. ✓Zuk et al [108,110] describes the use of perceptual and cognitive theories for uncertainty visualizations. Further, analyzes the support of uncertainty visualization in cognitive and meta-cognitive processes	✓ Multidimensional, multivariate, multi-valued[119,122]. ✓ Risk of cognition overload and the effectiveness and usability of uncertainty[151]. ✓ Uncertainty of a measurement, simulation or product[104]. ✓ Uncertainty in the experimental, simulation, and/or visualization processes[114]
Qualitative Data Visualization	✓To develop and demonstrate the principles of visualization for exploring qualitative data. ✓Eppler[123] presented a systematic overview of the formats available for describing classifications visually. ✓Henderson [125] reviews various techniques for visualizing qualitative data. ✓Slone[126] suggested to merge qualitative information with the human ability to derive understanding from graphics. ✓Mennis [128] studied the theoretical principles of combining qualitative and quantitative data. ✓Knigge [129] studied that how grounded theory and visualization might be used together to construct an integrated analysis strategy. ✓Verdinelli[130] review the data visualization methods used by three prestigious qualitative research journals within 2006-2009.	✓ To present quantitative data in visual form without oversimplifying or misrepresenting after pruning outliers is challenging [125].

VII. DISCUSSION AND CONCLUSION

The visualization is a way of presenting the vast data using graphical means that is helpful for users or decision maker to understand & interpreted data, grasp the inward or hidden nature of data, explore and analyze data and understand relationship between various constituents of data. Prior to the development of digital computer & interactive graphical interface, the traditional approaches such as expression, gesture, signal, visual symbol, map, painting, chart, poster, sign etc. were used to understand & convey the meaning of data in visual form. In modern era visualization is equipped with GUI that is not only easy to use and customizable but helpful for understanding complex data upto certain limit.

A lot of work has been done in various areas for visualization. Initially, the term visualization was limited to information and scientific visualization but it has been extended to other fields too. In our study we have conducted a survey of use of visualization in digital forensic, network security, data mining, uncertainty, risk management, knowledge management and qualitative data. The major challenge is to handle vast, complex, multi-dimensional, multi-source and time varying data in real time framework. The monitor screen can accommodate only a chunk of visuals in a single inning. Managing meaningful visuals on screen from appropriate data from vast data is still a problem. The other challenges are related to usability, scalability, universal acceptability and preserving quality of data while utilizing visualization tools.

REFERENCES

[1] E.R. Tufte, Envisioning Information, 1990. ISBN 0961392118.
[2] E.R. Tufte, Visual Explanations: Images and Quantities, Evidence and Narrative, 1997. ISBN 0961392126.
[3] E.R. Tufte, The Visual Display of Quantitative Information , 2nd ed., 2001. ISBN 0961392142.
[4] G. Kowalski and M.A. Maybur, Information Storage and Retrieval System, Theory and Implementation, Second Edition.
[5] M. Raffael, Applied Security Visualization, Addison-Wesley, 2008.
[6] Chris North , Toward Measuring Visualization Insight, IEEE Computer Society, 2006.
[7] R. L. Gregory, "Eye and Brain. The Psychology of Seeing", 4th ed., Princeton University Press, Princeton, NJ, 1990
[8] D. R. Lipsa, R. S. Laramee, et al, Data Representation for Scientific Visualization: An Introduction; http://cs.swan.ac.uk/~csbob/research/data/lipsa10data.pdf
[9] M. Ward, "Overview of Data Visualization", from www.cs.wpi.edu.
[10] U. Craig, F. Thomas et al, Scientific Visualization System: A Computational Environment for Scientific Visualization, IEEE Computer Graphics and Applications, pp 30-42, July 1989.
[11] M. Friendly, A brief history of data visualization, (2006)
[12] M. Friendly, Milestones in the history of data visualization: A case study in statistical historiography. In C. Weihs and W. Gaul, eds., Classification: The Ubiquitous Challenge, pp. 34–52, New York: Springer, 2005.
[13] J. W. Tukey, Exploratory Data Analysis. Reading, MA: Addison-Wesley,1977.
[14] http://www.comphist.org/computing_history/new_page_6.htm
[15] http://design.osu.edu/carlson/history/lesson2.html
[16] C. Herman, The Use of Faces to Represent Points in K-Dimensional Space Graphically, Journal of the American Statistical Association, Vol. 68, No. 342, Jun. 1973, pp. 361-368.
[17] G. T. Herman, H. K. Liu, Three-dimensional display of human organs from computed tomograms, Computer Graphics and Image Processing, Vol 9, No. 1, pp. 1-21, 1979.
[18] R. M. Baecker, Sorting Out Sorting: A Case Study of Software Visualization for Teaching Computer Science. In J.T. Stasko, J. Domingue, M. Brown, and B. Price, (Eds.), Software Visualization: Programming as a Multimedia Experience. MIT Press, pp. 369-381, 1998.
[19] M. Levoy , Display of Surfaces from Volume Data, IEEE Computer Graphics and Applications, Vol. 8, No. 3, May, 1988, pp. 29-37.
[20] M. Levoy and T. Whitted. The use of points as display primitives. Technical Report TR-85-022,The University of North Carolina at Chappel Hill, Department of Computer Science, 1985
[21] http://en.wikipedia.org/wiki/Information_visualization
[22] B. Tversky, Visualizing Thought, Handbook of Human Centric Visualization, Springer, 2012.
[23] S. Lowman and I. Ferguson , Web History Visualization for Forensic Investigations, Proceedings of Cyber forensics, June 2011
[24] J. Olsson, M. Boldt, Computer forensic timeline visualization tool, Digital Investigation, Vol. 6. pp 78–87, 2009.
[25] J. B. Baum, Windows Memory Forensic Data Visualization, Technical Report, DTIC Document, 2014.
[26] J. Ahlers and H. Weimer, Challenges in Interactive Visualization for Knowledge Management, Proceedings of the Sixth International Conference on Information Visualisation, 2002.
[27] *FTK-5;* accessdata.com/product-download/.../forensic-toolkit-ftk-version-5.5.
[28] F. Meng, S. Wu, J. Yang and G. Yu, Research of an e-mail forensic and analysis system based on visualization, Second Asia-Pacific Conference on Computational Intelligence and Industrial Applications, pp. 281–284, 2009.
[29] G. Schrenk, R. Poisel,"A Discussion of Visualization Techniques for the Analysis of Digital Evidence", International Conference on Availability, Reliability and Security, pp. 758 -763, 2011.
[30] T. R. Leschke and A. T. Sherman, Change-Link: A Digital Forensic Tool for Visualizing Changes to Directory Trees, in Proceedings of VizSec '12 , Seattle, WA, October 15, 2012.
[31] E. Vlastos and Ahmed Pate, An open source forensic tool to visualize digital evidence, Elseviser Computer Standards & Interfaces,2007.
[32] X. Liu, Y. Sun, L. Fang, J. Liu and L. Yu, A Survey of Network Traffic Visualization in Detecting Network Security Threats, Trustworthy Computing and Services, 2015, pp. 91-98.
[33] J.-N., Tioh, "FishEYE: A Forensic Tool for the Visualization of Change-Over-Time in Windows VSS", Eighth International Workshop on Systematic Approaches to Digital Forensic Engineering, 2013, pp. 1-7.
[34] B.K.L. Fei, Data visualisation in digtial forensics , M.S. Thesis, 2007.
[35] B.K.L. Fei, J.H.P. Eloff, H.S. Venter and M.S. Olivier, Exploring Data Generated by Computer Forensic Tools with Self Organizing Maps Advances in digital forensics, pp. 113-123. Springer 2006.
[36] S. K. Chavhan, S.M. Nirkhi, Visualization Techniques for Digital forensics: A Survey, International Journal of Advanced Computer Research, 2 Number-4 Issue-6 December 2012.
[37] S. K. Chavhan, S. M. Nirkhi and R.V. Dharaskar, Visualization of Data for Host-Based Anomalous Behavior Detection in Computer Forensics Analysis Using Self Organizing Map, International Journal of Computer Science and Technology, Vol. 4, Issue 2, April - June 2013.
[38] J. Okolica and G. L. Peterson,Windows systems agnostic memory analysis. Digital Investigation: The International Journal of Digital Forensics & Incident Response, Vol. 7, No. 1, 2010.
[39] J. Okolica and G. L. Peterson, Extracting Forensic Artifacts From Windows O/S Memory. Technical Report. Air Force Institute of Technology, 2011
[40] G. Osborne, The Explore, Investigate, and Correlate Process for Information Visualization in Digital Forensics. PhD dissertation. University of South Australia, 2012.
[41] G. Osborne, B. Turnbull and J. Slay, Development of InfoVis Software for Digital Forensics, IEEE 36th International Conference on Computer Software and Applications Workshops, 2012.
[42] R. Marty, Applied security visualization, Network World, January 23 2008.
[43] G. Palmer, A Road Map for Digital Forensic Research, First Digital Forensic Research Workshop (DFRWS), 2001.
[44] K. B. Abeyrathne, Y. M. P. K. B. Yaparathna, I. M. Illangarathne et al, Visualization Tool for Network Forensics Analysis Using an Intrusion Detection System– PSRS, Vol. 3, Dec 2009.
[45] K. Abdullah, Scaling and Visualizing Network Data to Facilitate in Intrusion Detection Tasks ,Phd. Thesis, School of Electrical and Computer Engineering ,Georgia Institute of Technology , May 2006.

[46] E. Karapistoli and A. A. Economides, Wireless Sensor Network Security Visualization, Proceedings of 4th International Workshop on Mobile Computing and Networking Technologies, 2012, pp. 850-856.
[47] J. Peng, C. Feng and J.W. Rozenblit, A Hybrid Intrusion Detection and Visualization System, Annual 13th IEEE International Workshop on Engineering of Computer Based Systems, 2006.
[48] N. H. Xu, H.Yang, F.Meng and L. Hu, A real-time intrusion detection security visualization framework based on planner-scheduler, Fourth International Conference on Innovative Computing, Information and Control, 2009, pp. 784-788.
[49] I. Elhenawy and A. E. Riad et al, Visualization Techniques for Intrusion Detection – A Survey , International Journal of Computer Science & Engineering Survey, Vol.2, No.3, August 2011.
[50] D. Ferebee and D. Dasgupta, Security Visualization Survey , Proceedings of the 12th Colloquium for Information Systems Security Education , University of Texas, Dallas, TX June 2 - 4, 2008.
[51] R. R. Kasemsri, A Survey, Taxonomy, and Analysis of Network Security Visualization Techniques. Thesis, Georgia State University, 2006.
[52] H. Shiravi, A. Shiravi, A. A. Ghorbani, A survey of Visualization Systems for Network Security, IEEE Trans Vis Computer Graphics, Vol. 18, No. 8, pp. 1313-1329, Aug. 2012.
[53] G. Conti, A Survey of Security visualization, Chapter 6, Security Data Visualization: Graphical Techniques for Network Analysis, William Pollock, 2007.
[54] B.-H. Chang and C. Y. Jeong, An Efficient Network Attack Visualization Using Security Quad and Cube, ETRI Journal, Volume 33, Number 5, October 2011.
[55] F. Zhou, R. Shi., Y. Zhao, Y. Huanga, and X. Liang, NetSecRadar: A Visualization System for Network Security Situational Awareness, Cyberspace Safety and Security , Lecture Notes in Computer Science, Volume 8300, 2013, pp. 403-416.
[56] W. Streilein, K. Kratkiewicz, M. Sikorski and K. Piwowarski, Seth Webster, PANEMOTO: Network Visualization of Security Situational Awareness Through Passive Analysis, Proceedings of the IEEE Workshop on Information Assurance United States Military Academy, 2007.
[57] J. Chen, Yulin Wang, et al, Real-time network security situation visualization and threat assessment based on semi-Markov process, Fifth International Conference on Machine Vision (ICMV 2012): Algorithms, Pattern Recognition, and Basic Technologies Wuhan, China , October 20, 2012.
[58] Y. Zhang , Y. Xiao, M. Chen, J. Zhang and H. Deng, A survey of security visualization for computer network logs, Security and Communication Networks, Vol. 5, Issue 4, pp. 404–421, April 2012.
[59] R. E. Etoty and R. F. Erbacher , A Survey of Visualization Tools Assessed for Anomaly-Based Intrusion Detection Analysis , Army Research Laboratory Adelphi, MD, April 2014.
[60] J. Zhang, G. Yang, L. Lu, M. L. Huang and M. Che, A Novel Visualization Method for Detecting DDoS Network Attacks, Visual Information Communication, 2010, pp. 185-194.
[61] D. A. Keim, Information Visualization and Visual Data Mining, IEE Transactions on Visualization and Computer Graphics, Vol 7, No 1, Jan-March 2002.
[62] D. A. Keim and H.-P. Kriegel, Visualization Techniques for Mining Large Databases: A Comparison, IEEE Trans. Knowledge and Data Eng., Vol. 8, No. 6, pp. 923-936, Dec. 1996.
[63] M. C. F. de Oliveira and H. Levkowitz, From Visual Data Exploration to Visual Data Mining: A Survey, IEEE Transactions on Visualization and Computer Graphics, Vol 9, No 3, July-Sept 2003.
[64] D. A. Keim and M. Ward , Intelligent Data Analysis, an Introduction by D. Hand and M. Berthold, chapter Visual Data Mining Techniques. Springer Verlag, Ed. 2nd, 2002.
[65] M. Ankerst, Visual Data Mining with Pixel Oriented Visualization Techniques, in ‘Proceedings of ACM SIGKDD Workshop on Visual Data Mining, San Francisco, 2001.
[66] [D. Y. Elke, A. Rundensteiner, M. O. Ward, Analysis Guided Visual Exploration of Multivariate Data, In Proceedings of Visual Analytics Science and Technology, 2007.
[67] P. N. Johnson-Laird, Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness. Harvard University Press, Cambridge, MA, 1983.
[68] D. A. Keim , J. Kohlhammer, G. Ellis, F. Mansmann, Mastering the Information Age: Solving Problems with Visual Analytics. Florian Mansmann, 2010.
[69] C. Madhavarapu, Visual Data Mining, Tutorial. http:// www3.cs.stonybrook.edu /~mueller/ teaching/ cse591_visAnalytics/ chidroop.pdf.
[70] K. Thangavel, EVISTA – Interactive Visual Clustering System, Academy Publishers, 2009.
[71] J. Duffy, Harvesting Experience: Reaping the Benefits of Knowledge, Prairie Village,KS: ARMA International, 1999.
[72] John P. Girard, Knowledge Management (KM) Definitions ; HTTP://www.JOHNGIRARD.NET/KM/.
[73] R. A. Burkhard, "Learning from Architects: The Difference between Knowledge Visualization and Information Visualization", Eight International Conference on Information Visualization , London, July 2004.
[74] S. Ya’acob, N. M. Ali, N.M. Nayan, Understanding Big Picture and Its Challenges: Experts and Decision Makers Perspective, Advances in Visual Information: Third International Visual Informatics, Springer, pp. 311-322, 2013.
[75] R. A. Burkhard, Towards a framework and a model for knowledge visualization: Synergies between information and knowledge visualization, Knowledge and information visualization, pp. 238-255, Springer Berlin Heidelberg, 2005.
[76] I.T. Medeni, S. Peker, M.E. Uyar, A knowledge visualization model for evaluating Internet news agencies on conflicting news, MIPRO, 2011 Proceedings of the 34th International Convention , pp 850-853, May 2011.
[77] R. A. Burkhard , M. Meier , Tube Map Visualization: Evaluation of a Novel Knowledge Visualization Application for the Transfer of Knowledge in Long-Term Projects , Journal of Universal Computer Science, vol. 11, no. 4, pp. 473-494,2005.
[78] R. A. Burkhard, M. Meier, P. Rodgers, M. Thomas, Jonathan Stott Knowledge Visualization: A Comparative Study between Project Tube Maps and Gantt Charts, Proceedings of 5th International Conference on Knowledge Management, pp. 388-395, Know-Centre, Austria, 2005.
[79] X. Bai, D. White and D. Sundaram, “The Contextual Adaptive Knowledge Visualization Environments”, The Electronic Journal of Knowledge Management Vol. 10 Issue 1, pp. 01-14; www.ejkm.com.
[80] M. R. Lee and T. T. Chen, From Knowledge Visualization Techniques to Trends in Ubiquitous Multimedia Computing, IEEE Symposia on Ubiquitous Multimedia Computing, pp. 73 – 78, Oct 2008.
[81] M.R. Lee, T. T. Chen, Visualizing Trends in Knowledge Management ,Knowledge Science, Engineering and Management, pp. 362-371, Lecture Notes in Computer Science, Springer-Verlag, 2007.
[82] M. Humphrey, S. J. Cunningham, I. H. Witten, Knowledge visualization techniques for machine learning, Intelligent Data Analysis, , Vol. 2, Issues 1-4, 1998, pp. 333–347
[83] T. Heide, L. Lis , Dynamic Knowledge Mapping: A Visualization Approach for Knowledge Management Systems, pp. 4001 – 4010, IEEE, 2012.

[84] M. J. Eppler and R. A. Burkhard, Visual representations in knowledge management: framework and cases, Journal of Knowledge Management, Vol. 11 No. 4, pp. 112-122, 2007.
[85] R. Biloslavo, T. B. Kregar, K Gorela, Using Visualization for Strategic Decision Making – A case of Salovenion Entrepreneurs, 13th European Conference on Knowledge Management, pp 83-90 , Spain , Sept 2012.
[86] W. Fang, Z. M. Cui, "Research on Knowledge Management Visualization of Deep Web", Key Engineering Materials, Vol. 439-440, pp. 189-194, Jun. 2010.
[87] B. Pinaud, P. Kuntz, F. Guillet and Vincent Philipp_e., Graphical Visualization in the Knowledge Management System Atanor. 6th International Conference on Knowledge Management, Gratz, Austria. 2006.
[88] http://eric-blue.com/2009/05/10/15-effective-tools-for-visual-knowledge-management/
[89] D.W. Hubbard, The Failure of Risk Management: Why It's Broken and How to Fix It. John Wiley & Sons, pp. 46, 2009.
[90] M. J. Eppler and M. Aeschimann, A Systematic Framework for Risk Visualization in Risk Management and Communication , Risk Management , Vol. 11, No. 2, April 2009, pp. 67-89
[91] F. Roth, Visualizing risk: the use of graphical elements in risk analysis and communications, Focal Report 9: Visualizing Risk, Risk and Resilience Research Group Center for Security Studies (CSS), ETH Zürich, 2012.
[92] A. Chandra and R. Krovi, B. Rajagopalan , Risk Visualization: A Mechanism for Supporting Unstructured Decision Making Processes, The International Journal of Applied Management and Technology, Vol 6, No. 4 , pp 48-70, 2007.
[93] S. Bresciani and M. J. Eppler , The Risks of Visualization A Classification of Disadvantages Associated with Graphic Representations of Information, ICA Working Paper 1/2008, February 2008
[94] T. E. D. Dyrseth , Visualizing Safety Indicators- A Study of Requirements, Department of Industrial Economics and Technology Management, 2013.
[95] M. J. Eppler, M. Aeschimann, Envisioning Risk A Systematic Framework for Risk Visualization in Risk Management and Communication, ICA Working Paper 5/2008, September 2008, Version 1.
[96] I. M. Lipkus, J. G. Hollands , The Visual Communication of Risk, Journal of the National Cancer Institute Monographs No. 25, pp. 149-163, 1999.
[97] A. M. Sharif, S. Basri and H. O. Ali, Strength and Weakness of Software Risk Assessment Tools, International Journal of Software Engineering and Its Applications Vol.8, No.3 , 2014, pp.389-398.
[98] J. Kontio, J.-P. Jokinen, and E. Rosendahl, Visualizing and Formalizing Risk Information: An Experiment, Proceedings of the 10th International Symposium on Software Metrics, 2004, pp. 196-206.
[99] H. H. Hosmer, Visualizing Risks: Icons for Information Attack Scenarios, Data Security, Inc., 2000.
[100] M. Hettig, E. Kiss, J.-F. Kassel, S. Weber, M. Harbach and M. Smith, Visualizing Risk by Example: Demonstrating Threats Arising From Android Apps, Symposium on Usable Privacy and Security, July 24–26(2013).
[101] D. Gresh, L. A. Deleris, and L. Gasparini, Visualizing Risk, RC25293 (IRE1206-005) June 20, 2012 Computer Science, IBM Research Division Thomas J. Watson Research Center, NY 10598 USA.
[102] K. Potter, S. Gerber, and E. W. Anderson, Visualization of Uncertainty without a Mean, IEEE Computer Graphics and Applications, pp. 75-79, 2003.
[103] http://www.businessdictionary.com/definition/uncertainty.html.
[104] G-P Bonneau, H-C Hege, C. R Johnson, M. M. Oliveira et al, Overview and State-of-Art of Uncertainty Visualization, Scientific Visualization: Uncertainty, Multifield, Biomedical, and Scalable Visualization, Springer, 2014.
[105] A. T. Pang, C. M. Wittenbrink, and S. K. Lodha, “Approaches to uncertainty visualization,” The Visual Computer, Vol 13, No. 8, pp. 370–390, 1997. ISSN 0178-2789.
[106] J. Thomson, E. Hetzler, A. MacEachren, M. Gahegan, and M. Pavel, A typology for visualizing uncertainty, in Proc. SPIE & IS&T Conf. Electronic Imaging, Visualization and Data Analysis, Vol. 5669, pp. 146–157, 2005.
[107] J. Sanyal, S. Zhang, G. Bhattacharya, P. Amburn, and Robert J. Moorhead, A User Study to Compare Four Uncertainty Visualization Methods for 1D and 2D Datasets, IEEE Transactions on Visualization and Computer Graphics, Vol 15, No. 6, pp 1209-1217, 2009.
[108] T. Zuk and S. Carpendale, Theoretical Analysis of Uncertainty Visualizations, Visualization and Data Analysis, edited by Robert F. Erbacher, Johnathan C. Roberts, Matti T. Gr¨ohn, Katy B¨orner, Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 6060, 2006.
[109] M. Riveiro, Evaluation of Uncertainty Visualization Techniques for Information Fusion,10th International Conference on Information Fusion, pp 1-8, Quebec , 2007.
[110] T. Zuk and S. Carpendale, Visualization of Uncertainty and Reasoning, LNCS 4569, pp. 164–177, Springer-Verlag, 2007.
[111] A. M. MacEachren, A. Robinson, S. Hopper, S. Gardner, R. Murray, M. Gahegan, and E. Hetzler, Visualizing Geospatial Information Uncertainty: What We Know and What We Need to Know, Cartography and Geographic Information Science, Vol. 32, No. 3, 2005, pp. 139-160.
[112] K. Potter, P. Rosen, and C. R. Johnson, From Quantification to Visualization: Taxonomy of Uncertainty Visualization Approaches, FIP Advances in Information and Communication Technology, Volume 377, 2012, pp 226-249.
[113] C. Collins, S. Carpendale, and G. Penn, “Visualization of Uncertainty in Lattices to Support Decision-Making,” in Proc. of Eurographics/IEEE VGTC Symposium on Visualization, Norrköping, Sweden, 2007.
[114] A.M. MacEachren, R.E. Roth, J. O’Brien, B. Li, et al, Visual Semiotics & Uncertainty Visualization: An Empirical Study, IEEE Transactions on Visualization & Computer Graphics , Vol. 18, Issue 12, Dec. 2012.
[115] F. Jiao, J. M. Phillips, Y. Gur and C. R. Johnson, Uncertainty Visualization in HARDI based on Ensembles of ODFs, IEEE Pac Vis Symp, pp. 193-200, Dec, 2013.
[116] P. Hermosilla, R. Brecheisen, P.-P. Vázquez and A. Vilanova , Uncertainty Visualization of Brain Fibers, CEIG - Spanish Computer Graphics Conference , 2012.
[117] M. Skeels, B. Lee, G. Smith, and George Robertson, Revealing Uncertainty for Information Visualization, AVI'08, 28-30 May 2008, Napoli, Italy.
[118] A-L. S. Lapinski, A Strategy for Uncertainty Visualization Design, DRDC Atlantic TM 2009-151; Defence R&D Canada –Atlantic, October 2009.
[119] A. Pang, Visualizing Uncertainty in Natural Hazards, Risk Assessment, Modeling and Decision Support, , Springer Berlin Heidelberg, pp 261-294, 2008.
[120] A. M. MacEachren, A. Robinson, S. Hopper, S. Gardner, et al, Visualizing Geospatial Information Uncertainty: What We Know and What We Need to Know. Cartography and Geographic Information Science, Vol. 32, Vol. 2, pp. 139-160, 2005.
[121] P. Goovaerts, Visualization and comparison of spaces of uncertainty using three dimensional display and multi-dimensional scaling, Multidisciplinary Research on Geographical Information in Europe and Beyond, Proceedings of the AGILE'2012 International Conference on Geographic Information Science, Avignon, April, 24-27, 2012.
[122] R. P. Botchen, D. Weiskopf, T. Ertl, Texture-Based Visualization of Uncertainty in Flow Field, Visualization, 2005, pp. 647-654.
[123] M.J. Eppler, J. Mengis, Drawing Distinction: The Visualization of Classification in Qualitative Research, No. 2, July 2011.
[124] I. Dey, Qualitative data analysis, A User Friendly Guide for Social Scientists, Routledge, Taylor & Francis Group, London and NewYork, 1993.

[125] S. Henderson, E. H. Sehgal, Visualizing Qualitative Data in Evaluating Research, Data Visualization: Part 1, New Directions for Evaluation, Number 139, In T. Azzam, S. Evergreen Eds., pp. 53-72, 2013.
[126] D. J. Slone , Visualizing Qualitative Information, The Qualitative Report Vol. 14 No. 3 September, 2009, pp. 489-497.
[127] K. Erwin, The Visual Coding of (Big) Qualitative Data: New Analytic Methods and Tools for Emerging Online Research, Proceedings of IASDR2011, the 4th World Conference on Design Research, Oct-Nov, 2011.
[128] J. Mennis, M. J. Mason and Y. Cao, Qualitative GIS and the visualization of narrative activity space data, International Journal of Geographical Information Science, Vol. 27, No. 2, pp. 267–291, Taylor & Francis Group, 2011.
[129] L. Knigge, M. Cope , Grounded Visualization: Integrating the Analysis of Qualitative and Quantitative Data Through Grounded Theory and Visualization, Environment and Planning, Volume 38, pp 2021 -2037, 2006.
[130] S. Verdinelli, N.I. Scagnoli, Data Display in Qualitative Research, International Journal of Qualitative Research, Vol. 12, pp. 359-381, 2013.
[131] M. Stone, Information Visualization: Challenge for the Humanities, in Working Together or Apart: Promoting the Next Generation of Digital Scholarship: Report of a Workshop Cosponsored by the Council on Library and Information Resources and the National Endowment for the Humanities, CLIR Publication, No. 145, pp. 43–56, 2009.
[132] C. Plaisant, Information Visualization and the Challenge of Universal Usability, Exploring Geovisualization (Eds. J. Dykes, A.M. MacEachren, M.-J. Kraak), Elsevier, 2005.
[133] S.Liu, W. Cui, Y. Wu, M. Liu and M. Liu, A survey on information visualization: recent advances and challenges, The Visual Computers, Volume 30, Issue 12, pp. 1373-1393.
[134] C. Chen, Information visualization, Volume 2, July-August 2010, John Wiley & Sons, Inc.
[135] C. Ziemkiewicz, R. Kosara, Embedded Information Visualization within Visual Representation, Advances in Information and Intelligent Systems, (Eds. William Ribarsky), Springer , 2009.
[136] Robert S. Laramee and Robert Kosara, Future Challenges and Unsolved Problems (in Human-Centred Visualization), Scientific Visualization, pp. 205-211, 2014.
[137] C. Chen, Top 10 Unsolved Information Visualization Problems. IEEE Computer Graphics and Applications, Vol. , No. 4, pp. 12–16, July-August 2005.
[138] S. A. Najim, Information visualization by dimensionality reduction: a review, Journal of Advanced Computer Science and Technology, Vol.3, No. 2, pp. 101-112, 2014.
[139] H. Childs, B. Geveci and W. Schroeder et al, Research Challenges for Visualization Software, 2013.
[140] J. Haggerty, D. Lamb and M. Taylor, Social Network Visualization for Forensic Investigation of E-mail, Proceedings of the Fourth International Workshop on Digital Forensics & Incident Analysis, 2009, pp. 81-92.
[141] http://tnv.sourceforge.net/ (Network Visualizer tnv).
[142] D. M. Best, A. Endert and D. Kidwell, 7 Key Challenges for Visualization in Cyber Network Defence, Proceedings of eleventh Workshop on Visualization for Cyber Security, 2014, pp. 33-40.
[143] J. R. Goodall, Introduction to Visualization for Computer Security, Proceedings of the Workshop on Visualization for Computer Security, Mathematics & Visualization, Springer Berlin Heidelberg, 2008, pp. 1-17.
[144] J. Fuchs, D. A. Keim, F. Mansmann, et al.: BANKSAFE: A visual situational awareness tool for large-scale computer networks: VAST 2012 challenge award: Outstanding comprehensive submission, including multiple vizes. Proceedings of the IEEE Conference on Visual Analytics Science and Technology (VAST), pp. 257–258, 2012.
[145] L. Harrison and A. Lu, The Future of Security Visualization: Lessons from Network Visualization, IEEE Network, 2012, pp. 6-11.
[146] D. A. Keim, F. Mansmann, J. Schneidewind, and H. Ziegler , Challenges in Visual Data Analysis, Proceedings of the Information Visualization, 2006.
[147] M. J. Eppler , What is an Effective Knowledge Visualization? Insights from a Review of Seminal Concepts, 15th International Conference on Information Visualisation, 2011.
[148] S. Bertschi, S. Bresciani, T. Crawford, Randy Goebel et al, What is knowledge Visualization? Eight reflections on evolving discipline, Knowledge Visualization Currents, From Text to Art to Culture, Springer London, 2013, pp. 13-32.
[149] R. Meyer, Knowledge Visualization, Media Informatics Advanced Seminar on Information Visualization, 2008/2009.
[150] C. R. Johnson and A. R. Sanderson, A next step: Visualizing errors and uncertainty. IEEE Computer Graphics and Applications, Vol. 23, No. 5, pp. 6-10, 2003.
[151] K. Alberti , Web-based Visualization of Uncertain Spatio-temporal Data, Utrecht University, 2013.
[152] Y. Park and J. Park, Web Application Intrusion Detection System for Input Validation Attack , Third International Conference on Convergence and Hybrid Information and Technology, Vol 2, pp.498-504 , Nov 2008.

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