Web-based Information Visualization Using JavaScript

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Since the available digital information grows rapidly, the utilization of the information visualization becomes of utmost importance to perform complex data analysis tasks. With the help of the visualizations, hidden facts about the data such as patterns, outliers and tendencies can be revealed. Strategic decisions can be established with the insights gained during the interactive data exploration.

The latest developments in browser technology have enabled developers to build interactive web-based visualizations to target broader audience. This thesis is dedicated to investigate usage of JavaScript in web applications. After describing the main theories and frameworks in the information visualization literature, a number of visualization tools are introduced. D3.js is selected as the visualization framework to visualize Tampere Unit for Computer-Human Interaction Research Center's publication data.

According to design considerations and experiment gained from visualization of the web-based publication data, it is possible to create powerful and reusable interactive visualizations with JavaScript frameworks. Theories and frameworks mentioned in the literature review worked as a guideline while visualizing the web-based data.

Key words: information visualization, web-based visualization, JavaScript and information visualization

Contents

1. Introduction

Information visualization is an emerging discipline that utilizes visual representations of abstract data to help people to understand the underlying meanings of the information. Visual data observation makes more sense on human beings than looking at the raw information. In today's big-data world, meta-information, i.e., information about the information, has become more important. While dealing with the data, information visualization not only appeals to the eyes, but also has a potential to reveal the hidden information.

When William Playfair [1801] invented the pie chart, he already discovered that alluring the eye makes people read the information easily. He chose to display series of circles arranged side by side with their centres aligned where some of the circles were divided into sectors (See Figure 1.1). Although the effectiveness of the chosen method is questionable by some researchers (e.g., Stephen Few [2007]), pie charts can still be regarded as one of the most popular ways to display information.

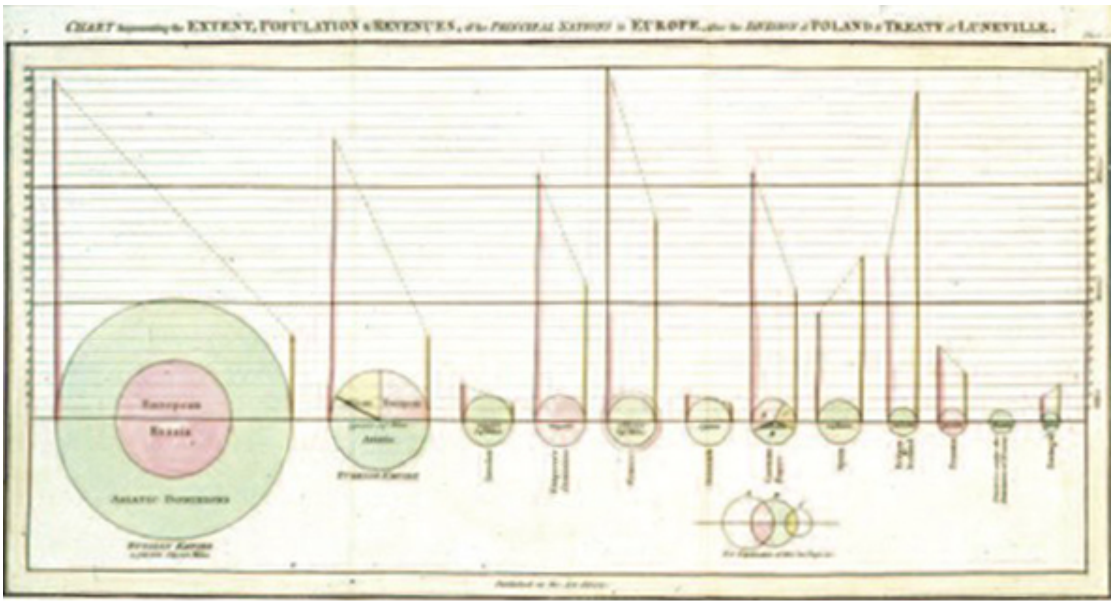


Figure 1.1 The first pie chart ever from William Playfair's "Statistical Breviary" [1801]

After Playfair's invention, historical examples vary with Napoleon's Russian campaign of 1812 [Tufte, 2001] and John Snow's map that represents the cholera clusters of the epidemic data [Johnson, 2006]. In addition to the historical examples demonstrating the earlier usage of visualization tools, *The Joy of Stats* by Hans Rosling [2010] revealed how information visualization can be applied creatively to demonstrate big quantities of public data. Rosling visualized the development story of the world using augmented reality animation. He illustrated how modern technology can be used to visualize mass amounts of data.

Although Rosling's visualization was a good example to demonstrate big amounts of data, it was lacking to provide a platform where people could interact with the data. In today's Internet of Things world, devices are connected with each other within the Internet infrastructure. Web browsers are widely being used to retrieve, present and traverse information on the World Wide Web.

One of the most common applications of information visualization can be regarded as visualizing web-based information due to the increasing power of web browsers. Today's interactive and mobile-friendly visualizations require responding to the user actions such as clicking, hovering, scrolling and touch gestures. Users want to navigate through data and filter the information according to their needs. Nowadays web browsers are responsible for data processing instead of servers because of the increased demand for real-time interactivity.

Since JavaScript is the language of web browser, it is commonly used while visualizing the data. Client-side JavaScript, i.e., JavaScript interpreter embedded in a browser, combines scripting capabilities of JavaScript together with the document object model (DOM) presented by the browser.

Client-side JavaScript enables users to control document appearance and content, interact with HTML forms and other users. This approach has both advantages and disadvantages. Since JavaScript code is executed on the user's computer, processing is fast as there is no need to process data in server. JavaScript also provides an extended functionality for web pages so that developers can customize the visualization and behaviour of the websites. Although advantages of using JS in web browsers are varied, there are some related drawbacks. JavaScript frameworks, which are being used to extend functionality, might raise security issues since they execute on client side immediately. Moreover, inconsistencies between different layout engines might lead to functionality and interface variations. This disadvantage doesn't afflict the web-based visualization using JavaScript since most of the modern browsers support the latest versions of JavaScript.

This thesis mainly focuses on the usage of JavaScript in web applications. The main purpose of this work is to examine JavaScript visualization frameworks. After examining the important theories and frameworks in the process of information visualization, example web-based applications will be examined with regard to these theories and frameworks. Lastly, Tampere Unit for Computer-Human Interaction's (TAUCHI) publication data will be visualized with selected JavaScript framework to demonstrate the strength of JavaScript in web-based applications.

This thesis consists of six chapters. Chapter 2 introduces the main principles and concepts of information visualization. This is followed by a detailed discussion on the web-based information visualization and usage of visualization tools. Chapter 3 focuses on the selected visualization framework, D3.js, and demonstrates the application of this framework to the recent web based visualization examples. Chapter 4 explains the implementation details of the TAUCHI's publication data and implementation results can be seen in Chapter 5. In the conclusion chapter, visualization of the TAUCHI's publication data will be discussed regarding the theories and frameworks mentioned during the literature review.

2. Information Visualization using JavaScript

This chapter discusses the main principles of information visualization and describes web-based information visualization regarding the current visualization tools. Lastly, usage of JavaScript in the field of information visualization is introduced in detail.

2.1. Information Visualization

Information visualization is a research area that aims to allow people to gain insight, understand and analyse the data. According to a dictionary, ‘visualize’ means “to form a mental image, to make something visible”. Vast quantities and different types of information are being generated these days, emerging the need to extract information from data overload.

Card et al. [1999] describes information visualization as the use of computer-supported, interactive, visual representations of abstract data to amplify cognition. One of the main goals of information visualization can be regarded as augmenting human cognition in a way that viewers gain knowledge about the underlying meaning of the data.

Information visualization influences the lives of humankind directly. To exemplify, people need to search through various information such as metro lines, e-mails and schedules on a daily basis. Finding the valuable information hidden in large amounts of data can be a difficult task. Therefore, adequate exploration of data enables people to make use of the data.

As information visualization is an evolving discipline, historical examples indicate the significance of the different visualization techniques. In 1931, Harry Beck, engineering draftsman, altered and improved London Underground Tube map [Degani, 2013]. He eliminated all of the surface details except the Thames River that brought simplicity to his drawing. The result was so simple and comprehensible that society embraced his map and it became an essential guide to London. Beck’s revolutionary design with modifications and additions survives to the present day.

Although Harry Beck prepared striking Tube map to display available information, lack of proper visualization techniques caused some disasters in the history. In 1986, Space Shuttle Challenger exploded 73 seconds after its launch causing the death of seven US astronauts. The reason for the explosion was the failure of an O-ring seal on a booster rocket due to the cold weather. Edward Tufte, noted statistician in the field of data visualization, indicates that inaccurate assessment of the facts lead to the explosions. Although design engineers prepared 13 charts supporting the launch, they couldn`t display the relationship between O-ring failure and temperature. Tufte even claims that this tragic accident might have been avoided with a clear representation. [Robinson et al., 2002]

Impact of information visualization in today`s world is increasing as generated digital content is also expanding. One of the important aspects of information visualization can be regarded as interactivity. Visual representation of the data allows viewers to gain insight of the data and reach conclusions by directly interacting with the data. Viewers can interact with the data intuitively without requiring understanding of the underlying structures. It is crucial to understand the information visualization process while creating interactive web-visualizations. User friendly, highly interactive and reusable charts can be created if designers convey to the main principles of information visualization.

2.1.1. Data Types and Information-Seeking Mantra

The terms data, information and knowledge are being extensively used in the field of information visualization. It is important to differentiate these terms to be able to understand data types better.

Russell Ackoff, organizational theorist, classifies the content of the human mind into five categories: data, information, knowledge, understanding and wisdom [Ackoff, 1989]. He defines data as symbols. Data can exist in any form independent of its usability. He describes information as the data that is processed to be useful. Information provides answers to “who”, “what”, “where” and “when” questions. He further characterizes knowledge by stating that knowledge provides answers to “how” questions, as knowledge is the application of data and information. Ackoff [1989] continues his definitions by stating that understanding is the appreciation of “why” whereas wisdom is the evaluated understanding.

Ackoff [1989] makes distinction between data and information in perceptual and cognitive space. It is also important to make the distinction in computational space since data and information can be stored in a computer. Data is defined as computerized representations, whereas information is the data that represents the results of a computational process [Chen et al., 2009].

Although one can categorize data in many ways (e.g., nominal, ordinal, interval), Shneiderman [1996] discusses about the data type taxonomy with seven data types (one, two, three dimensional data, temporal data, multi-dimensional data, tree and network data) and seven tasks (overview, zoom, filter, details on demand, relate, history and extract). Shneiderman`s Visual Information-Seeking Mantra [Shneiderman, 1996] provides a framework for designing information visualization applications.

According to Shneiderman [1996], data types can be described as follows:

- *One-dimensional data:* Consists of linear data types (e.g., textual documents which are sequentially organized).
- *Two-dimensional data:* Includes planar or map data where each item in the collection corresponds to some part of the area. Every item includes task-domain attributes.
- *Three-dimensional data:* Includes real world objects. Understanding the position and orientation of the object is one of the challenging tasks of the viewers.
- *Temporal data:* Consists of items which has a start and finish time where timelines are needed (e.g., medical records, project management).
- *Multi-dimensional data:* Items with n-attributes relate with points in an n-dimensional space. Common user tasks include, for instance, finding patterns, correlations and outliers.
- *Tree data:* In a tree hierarchy, each item has a link to the parent item except from the root. Finding the number of levels in a tree can be one of the major user tasks.

- *Network data:* Includes items linked to an arbitrary number of other items where these items cannot fit into a tree conveniently (e.g., visualizing the social networks).

After defining different data types, Shneiderman [1996] states his mantra to achieve powerful visualizations: overview first, zoom and filter, then details on demand. This mantra provides designers a framework and explains the essential elements of interacting with different types of data. Details about his mantra can be seen in below [Shneiderman, 1996]:

- *Overview:* Provides a general context for understanding the whole dataset. Patterns and themes can be observed from this viewpoint.
- *Zoom and Filter:* Once the data is presented to the user with overview, viewers can focus on the particular area depending on their interest. Zooming allows users to adjust the size and the position of the data on screen where filtering removes the irrelevant information.
- *Details on demand:* Viewers should be able to observe the raw data if they demand. Visualization application should not enforce the users to change the view to be able to see the details.
- *Relate:* Users can observe the relationships between the items. For instance, users of HomeFinder [Williamson and Shneiderman, 1992] could select an attribute garage, to find the houses with a garage in a price range and area relating the houses only with a garage.
- *History:* Viewers should be supported with undo and replay options to provide historical information to the users.
- *Extract:* Once the user has found the related information by overviewing first, zooming and filtering, and then details on demand, it would be useful to enable users to save the relevant information by extraction.

Despite the fact that there are different data types, designers can cope with these different types of data by applying the Visual Information-Seeking Mantra [Shneiderman, 1996]. Shneiderman`s Mantra provides an efficient guideline to achieve successful visualizations. Frequent use of the Mantra could be an indication that overview first, zoom and filter, then details on demand approach provides strong visualizations under different scenarios with different data types.

2.1.2. Goals of the Information Visualization

The main goals of information visualization mainly focus on making viewers gain insight by forming a mental model. As information visualization includes human interaction with the data, main aim of information visualization is to acquire the viewer with the knowledge. It has been proven that information visualization works as a learning tool to foster knowledge acquisition. Experiment that investigates the understanding of the relations in a data set leads to the conclusion that cognitive processes in knowledge acquisition can be enhanced by applying information visualization techniques. [Keller et al., 2006]

The main goals of information visualization can be listed as discovery, decision-making and explanation. Each of these goals, explained as follows, plays a significant role in gaining insight:

- *Discovery:* Information visualization provides metadata, i.e., data about the data. Therefore, it is possible to create hypotheses without investigating all bits of the data. Exploratory data analysis is a data analysis approach which utilizes mostly graphical techniques such as box plots, histograms and scatter plots. Tukey [1977] defines exploratory data analysis in 1962 as: "Procedures of analyzing data, techniques for interpreting the results of such procedures, ways of planning the gathering of data to make its analysis easier, more precise or more accurate …". Viewers can make discoveries by finding outliers, tendencies and trends with the help of the exploratory analysis. Viewers can also formulate hypotheses and verify or refute the hypotheses.
- *Decision-making:* After deriving hypotheses about the data, information visualization aims to provide confirmative analysis. For example, Dr. John Snow`s main hypothesis was that cholera spreads through water [Johnson,

2006]. In order to prove his hypothesis, he mapped the number of deaths, which lead to the confirmation of his hypotheses (See Figure 2.1).

Figure 2.1 Original map by John Snow demonstrating the cholera clusters in London epidemic cases of 1854 [Johnson, 2006]

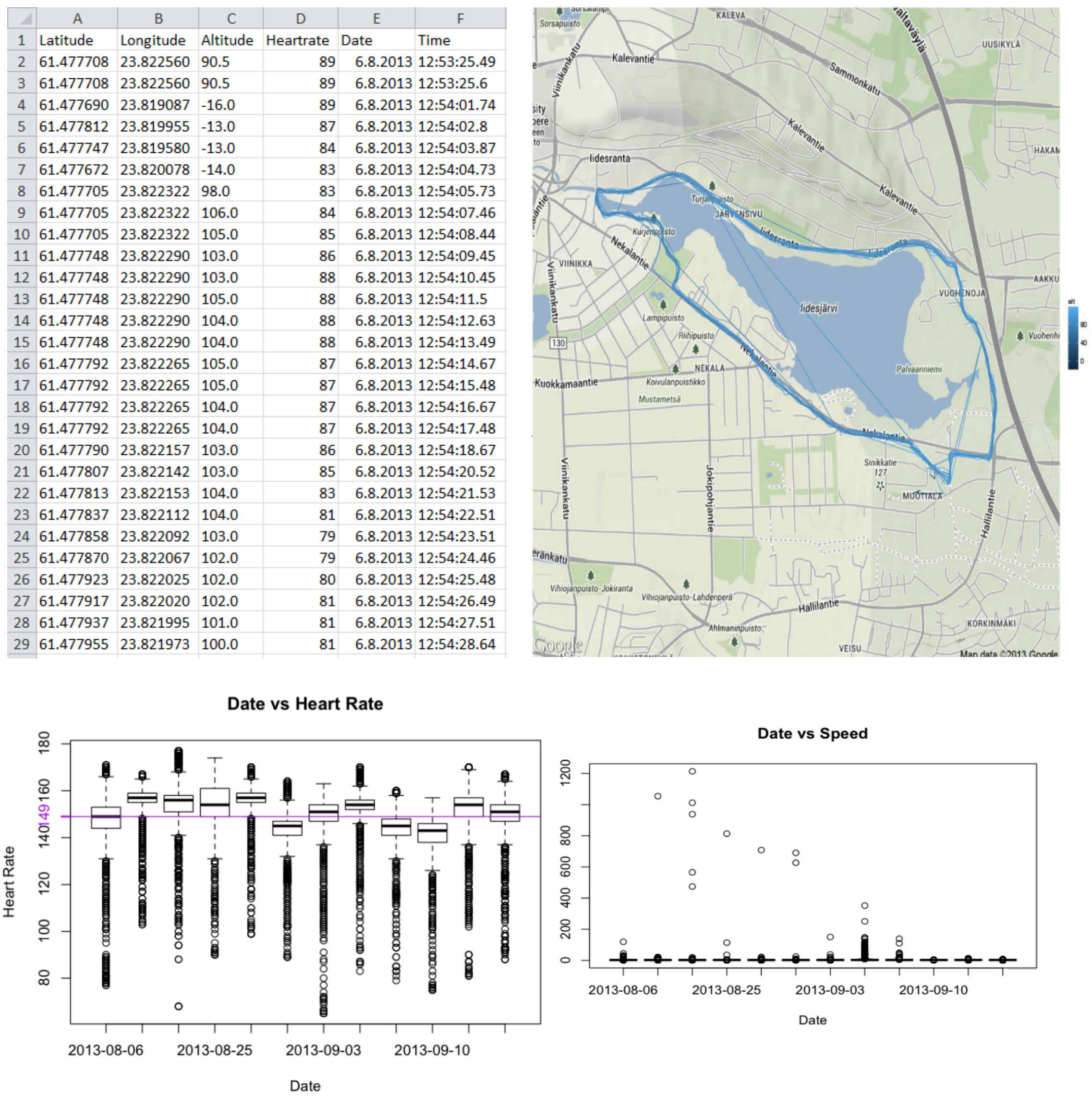
In contrast to the exploratory data analysis, confirmatory analysis begins by stating a hypothesis. Examination of the hypothesis is achieved in a goal-oriented manner. Visualization either confirms or rejects the hypothesis as a result.

- *Explanation:* Another goal of information visualization is to present the fact which results in high-quality visualization of the data. Presentation serves the purpose of delivering the results of an analysis efficiently and effectively. User selects the appropriate presentation technique, determining the facts to be presented beforehand.

Observers gain insight by discovery, decision-making and explanation. Information visualization aims to acquire the observers with knowledge. Viewers can make new discoveries simply by finding outliers, detecting trends and tendencies. They can also refute or accept hypothesizes by observing or interacting with the data. Large quantities of data can be explained to the viewers so that they can understand the underlying meanings of the data.

2.1.3. Gaining Insight

Human vision contains millions of neurons where each individual neuron works in parallel to extract the features of visualization. This rapid parallel processing and pattern recognition happen regardless of human attention [Ware, 2004]. Visualization means the formation of a mental model or cognitive map of the data [Spence, 2014]. Visualization is perceived in mind and results in mental model or internal model, i.e., cognitive maps.



	A	B	C	D	E	F
1	Latitude	Longitude	Altitude	Heartrate	Date	Time
2	61.477708	23.822560	90.5	89	6.8.2013	12:53:25.49
3	61.477708	23.822560	90.5	89	6.8.2013	12:53:25.6
4	61.477690	23.819087	-16.0	89	6.8.2013	12:54:01.74
5	61.477812	23.819955	-13.0	87	6.8.2013	12:54:02.8
6	61.477747	23.819580	-13.0	84	6.8.2013	12:54:03.87
7	61.477672	23.820078	-14.0	83	6.8.2013	12:54:04.73
8	61.477705	23.822322	98.0	83	6.8.2013	12:54:05.73
9	61.477705	23.822322	106.0	84	6.8.2013	12:54:07.46
10	61.477705	23.822322	105.0	85	6.8.2013	12:54:08.44
11	61.477748	23.822290	103.0	86	6.8.2013	12:54:09.45
12	61.477748	23.822290	103.0	88	6.8.2013	12:54:10.45
13	61.477748	23.822290	105.0	88	6.8.2013	12:54:11.5
14	61.477748	23.822290	104.0	88	6.8.2013	12:54:12.63
15	61.477748	23.822290	104.0	88	6.8.2013	12:54:13.49
16	61.477792	23.822265	105.0	87	6.8.2013	12:54:14.67
17	61.477792	23.822265	105.0	87	6.8.2013	12:54:15.48
18	61.477792	23.822265	104.0	87	6.8.2013	12:54:16.67
19	61.477792	23.822265	104.0	87	6.8.2013	12:54:17.48
20	61.477790	23.822157	103.0	86	6.8.2013	12:54:18.67
21	61.477807	23.822142	103.0	85	6.8.2013	12:54:20.52
22	61.477813	23.822153	104.0	83	6.8.2013	12:54:21.53
23	61.477837	23.822112	104.0	81	6.8.2013	12:54:22.51
24	61.477858	23.822092	103.0	79	6.8.2013	12:54:23.51
25	61.477870	23.822067	102.0	79	6.8.2013	12:54:24.46
26	61.477923	23.822025	102.0	80	6.8.2013	12:54:25.48
27	61.477917	23.822020	102.0	81	6.8.2013	12:54:26.49
28	61.477937	23.821995	101.0	81	6.8.2013	12:54:27.51
29	61.477955	23.821973	100.0	81	6.8.2013	12:54:28.64

Figure 2.2 Training dataset [Siirtola, 2013] shown in spreadsheet, geographical and boxplot forms using R software

For instance, Figure 2.2 demonstrates the mapping of the training data which includes latitude, longitude, altitude, date, and time information. The training terrain, altitude differences, average heart rate and highest speed can be inferred from the visualizations. It is not possible to gain these insights only by observing the raw dataset. Although these insights aren`t explicitly stored in the data, they are gained through pattern recognition. Therefore, visual representation plays an important role in gaining insight. Visualizations can hide the meanings or mislead the viewers unless data is visualized accurately.

Yi et al. [2008] claim that there are certain procedures leading to insight. These procedures are as follows:

1. *Provide overview:* Viewers can discover the overall picture of the data with this process. Further inquiries needs to be done on the dataset can be determined during this step by grasping knowledge about the data comprehensively.
2. *Adjust:* Observers can change the level of abstraction and selections in a flexible manner. This way, large quantities of data can be explored using filtering. Additionally, uninteresting parts of the data can be omitted.
3. *Detect pattern:* Specific distributions, outliers and relationships in the dataset can be found by detecting patterns. New knowledge discoveries can be made by recognizing patterns within the dataset.
4. *Match mental model*: Cognitive load in the process of knowledge acquisition can be reduced by linking the data with the viewer`s mental model. Metaphors can provide more effective mapping while matching the data with the mental model.

Information visualization is a strong tool for the knowledge discovery. Additional to simple insights such as minimum, maximum or average values, complex insights as patterns, clusters, paths can be derived from information insight. Viewer`s internal model can be refined, clarified and extended by gaining insight.

2.1.4. Activity of Information Visualization

Considering the fact that information visualization enhances the ability to comprehend huge amounts of data, there are various differences in visualizations such as interaction paradigms and different data types. Although there are divergences in different visualizations, it is conceivable to analyse visualizations systematically.

Ware [2004] separates the process of data visualization into four: collection and storage of data, pre-processing and transporting the data into human-readable format, displaying the image on screen, and finally the perceiver (see Figure 2.3).

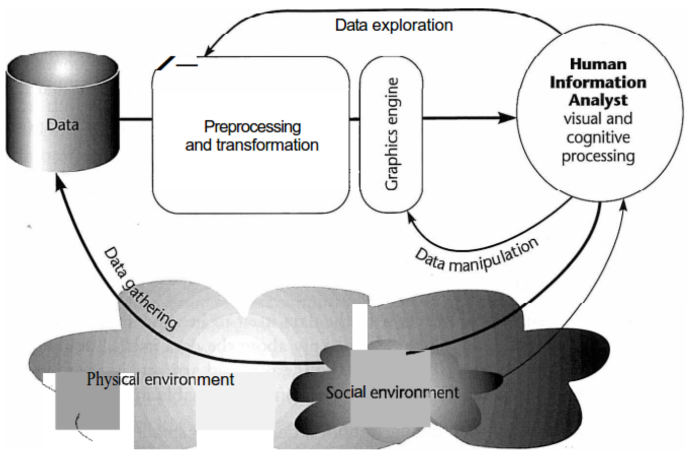


Figure 2.3 A schematic diagram of the visualization process [Ware, 2004]

Data is gathered from both physical and social environments. After data is collected, it needs to be pre-processed and transformed into organized canonical data format. At this stage, data entities need to be associated with attribute values. Graphics engine is responsible for mapping the dataset into visual form. Once the visual forms are created, views need to be provided to present transformations (e.g., navigation). Views are interpreted by users through human visual system, visual and cognitive processes.

Although Ware [2004] explains the process of information visualization, it lacks the ability of providing a platform to compare and contrast different information visualization systems. Different reference models were developed to simplify the discussion of different visualization systems by making correlations.

2.1.5. Reference Model for Visualization

Card et al. [1999] established a reference model by defining the milestones in the process of information visualization (see Figure 2.4). Reference model aims to provide a framework for developers who create new visualizations.

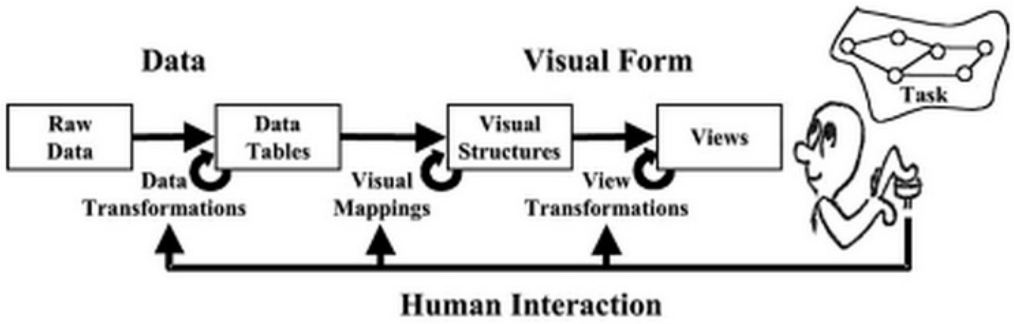


Figure 2.4 Reference model for visualization [Card et al., 1999]

According to the Card et al.`s model, raw data needs to be transformed into structured data using data tables. Data tables contain the metadata. Further transformations can be performed on metadata to derive additional characteristics of the data. Visual mappings constitute to the core of the reference model by converting data tables into visual structures. Visual structures are abstract, representing the derived characteristics of the data, which undergoes to the visual mappings. At this stage human vision can process the visual structures, whereas data tables were representing the mathematical relations. Once the visual structures are created and graphical views are acquired by view transformations, human interaction can alter the views (e.g., colour, size and orientation).

According to the Card et al.`s model (Figure 2.4), human interaction can take part at any stage of the visualization process. User selects the relative raw-data in the data transformations stage. During the visual mappings, user determines the mapping between the data variables and abstract structures (e.g., axes). User can interactively control the presentation of data, for instance, by distorting at the view transformations stage.

Although Card et al.`s [1999] reference model provides a step-by-step description on how to visualize raw data and how to include human interaction during the visualization process, this model lacks to provide detailed information for the developers. This lack of information is being criticized by some researchers. Chi [2000] criticizes the previous reference models by stating "Researchers have attempted to construct taxonomies of information visualization techniques by examining the data domains that are compatible with these techniques. However, these taxonomies do not help the implementers understand how to apply and implement these techniques". After this criticism, Chi proposes a new way to taxonomize information visualization techniques by providing an overview (See Figure 2.5) to his earlier Data State Model [Chi and Riedl, 1998].

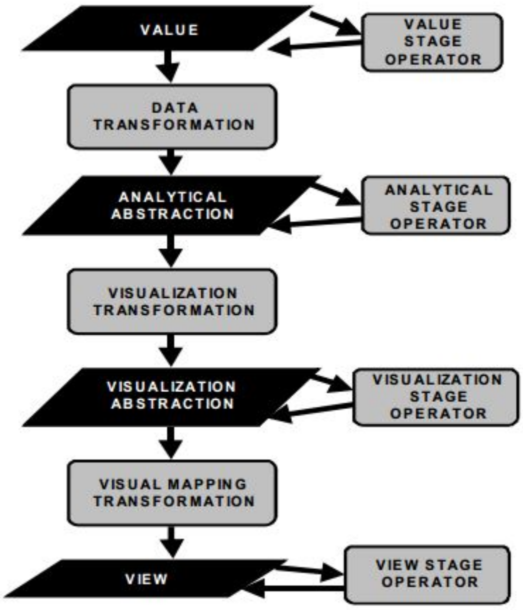


Figure 2.5 Information Visualization Data State Reference Model [Chi and Riedl, 1998]

There are four data stages in Chi`s Data State Model [Chi, 2000]: value, analytical abstraction, visual abstraction and view. Value corresponds to the raw data whereas analytical abstraction represents the metadata. Visualization abstraction means the information that can be visualized on screen using visualization techniques. User interacts with the view as it is the end-product. Data transformation, visualization transformation and visual mapping transformation operators have similar tasks as in the Card et al.`s Reference Model [Card et al., 1999].

Chi uses this Data State Reference Model to taxonomize different visualization techniques. For instance, one of the visualization techniques called GraphViz [AT&T, 2014] can take a graph as a raw data and remodel the graph by extracting edges and nodes during the data transformation stage. Complex graph layout algorithm places the nodes on a 2D plane during the visual mapping transformation stage. Chi [2000] gives many examples like GraphViz to provide sequential order of operations so that developers can create modular visualizations.

Although both of the Card et al.`s and Chi`s reference model and taxonomies share similar techniques to allow reuse, Chi puts more emphasize on the implementers so that they can understand how to apply these techniques broadly. Both of the Reference Model and Data State Model are important while analysing the information visualization activities. These models can be utilized to present further categorization to identify similarities between different visualization techniques.

The most important aspect of using reference models can be reuse. If designers can understand how to apply and implement information visualization techniques, they can reuse different parts of the system to construct new information visualizations. Reuse leads to the rapid development that brings broad benefits. Implementers are more likely to construct new visualizations if they understand the interactions between the data and operations clearly. Therefore, usage of reference models leads to rapid development.

2.2. Web-based Information Visualization

Utilization of information visualization becomes crucial when dealing with complex data sets. Data, information, users and applications work interactively in a distributed environment with the latest developments in browser and internet technologies. Web-based information visualization has a broad target group as there is no necessity for installing software to operate on the data. Users can interact with the up-to-date data without relying on the platform. Collaborative data analysis can be possible as most of the modern web browsers support the implementation of visualizations without requiring any other software installation.

There are different tools and technologies for developing interactive web-based visualizations. Before the improvement of browser technologies, small applets were the major visualization tools. These applets required third-party installations like Java Applets or Adobe Flash. Although there are still some tools requiring software installation, web-based visualizations tools tends to work in browser natively. Different visualization tools are explained in detail in the following chapters.

2.2.1. Visualization Tools

Bostock and Heer [2009] divide data visualization tools into two to make better comparison between the visualization tools as follows:

1. *Graphical Systems:* In this kind of systems, cognitive mapping between the representation and results accomplished directly since designers manipulate the graphical visualization using the selected software tool (e.g., vector-based Adobe Illustrator). Although higher-level tools like Adobe Flash provides illustration and animation, constructing even simple visualizations with these systems requires advanced design and programming skills.

2. *Visualization Systems:* Bostock and Heer [2009] describe these systems as tools that are designed for explicit data visualizations. These tools support data-management, layout algorithms, interaction and animation.

    a. *Consumer Software:* This category includes the most commonly used visualization tools such as Microsoft Excel and Google Spreadsheets. Some of the main tasks include the selection of relative data cells and determining the desired type of the chart. Although this kind of software is considered as successful in terms of ease of use and immediate visualization, there are some short comes mentioned by Wilkinson [2005]. He argues that chart metaphor is restrictive, disabling the user from understanding what to do with the data after constructing the visualization. He continues his arguments that charts give the impression of data exploration rather than the experience.

b. *Analytical and Exploratory Tools:* These types of tools are designed for providing flexible options for data explorations. Statistical programming language R can be regarded as an example for such tools. R has specific data visualization packages to replace base graphics with scales and layers. Although analytical and exploratory tools utilize the metadata by choosing appropriate visual encodings, it is not possible for designers to customize all visual aspects. Additionally, graphical output is mostly being used for research purposes rather than presentation since control over graphical output is limited [Bostock and Heer, 2009].

c. *Programming Toolkits:* According to Bostock and Heer [2009], programming toolkits are popular for presenting live data and allowing user interaction. Some of the toolkits (e.g., Google Chart API) support limited number of chart types, presenting similar characteristics with consumer software. More expressive visualization toolkits (e.g., InfoViz [Li, 2012]) allow extensions by modifying existing components or creating new components from scratch. On the other hand, Prefuse and Flare [Chi and Riedl, 1998] conveys the Chi`s Data State Model [2000], i.e., designers can specify properties of configurable operators to perform actions such as layout and color encoding. However, these kinds of toolkits transform easy tasks into complex ones [Bostock and Heer, 2009].

According to Bostock and Heer [2009], there is no strict distinction between graphical systems and visualization systems. Graphical systems use low-level graphical components whereas visualization systems utilize high-level abstractions designed for data visualization. Protovis, Bostock and Heer`s [2009] solution, adapts properties of both graphical and visualization systems. Protovis runs natively in the browser, but also allows declarative specification so that other rendering engines (e.g., Java2D, Flash) can be integrated in the future. With this approach they aim to optimize the Data State Model [Chi, 1998] through lazy evaluation of visual properties of large datasets.

2.2.2. Web-based Visualization Tools

In this section selected tools for web-based information visualization will be described considering the recent developments in web tools.

2.2.2.1 SVG

Scalable Vector Graphics (SVG) is an XML-based image format with support for interactivity and animation. World Wide Web Consortium (W3C) explicitly recommends the usage of SVG in web browsers [W3C, 2011]. It is possible to integrate SVG with other W3C standards like Document Object Model (DOM).

SVG is being used to define vector-based 2D web graphics in XML format. Since it is vector based, image size and scale can be changed without quality loss. As the images are scalable, they can also be zoomed without deterioration. Since SVG objects are available in DOM, JavaScript event handlers for the objects can be created, for instance, when the user clicks on a certain circle.

Every drawn shape is considered as a SVG object. When the user changes the attributes of an object, web browser re-enders the shape automatically. Therefore, usage of SVG is suited for the applications for large rendering areas like Google Maps.

Although SVG brings benefits like scalability, it is not widely supported. Intensive research needs to be carried out after creating a SVG image to ensure the image will appear and function as intended through different kinds of browsers. Additionally, SVG is not suitable for graphic-intensive applications as complex SVG images render slowly in the browser.

2.2.2.2 HTML5 Canvas

The Canvas Element is part of the HTML5 and enables dynamic rendering of 2D shapes. Canvas element with *height* and *width* attributes creates a container for the shapes. JavaScript code can access the specific canvas area while dynamically generating the graphics.

Canvas API is a low level pixel-oriented model. Shapes cannot be changed without overwriting the pixels. Unlike an SVG-object, once the shape is drawn, system forgets the fact that shape was drawn. As there is no automatic rendering with the Canvas element, entire shape would need to be redrawn if its shape or position is changed. Additionally, unlike SVG, it is not possible to create event handlers for Canvas elements, e.g., coordinates need to be matched manually to determine mouse click events. Canvas is suited better for graphic-intensive applications as it is more memory-efficient compared to SVG.

2.2.2.3 JavaScript

JavaScript (JS) is considered as the programming language of the web as most of the modern HTML pages are using JavaScript. Main usage of JS is the client-side JavaScript where users control and alter the document content in a web browser.

JS program can manipulate the *content* through containing Document and Element objects. *Presentation* of the content can be changed by scripting CSS styles. Additionally, event handlers can change the *behaviour* of documents. Combination of scriptable content, presentation, and behaviour is called Dynamic HTML (DHTML) [Flanagan, 2011]. Scripts embedded in HTML pages interact with the Document Object Model (DOM) directly to alter the page content dynamically.

JavaScript can be utilized to enhance the browsing experience, for example, by creating animations, playing audio/video and validating input values. Additional to content, presentation and behaviour manipulation, JavaScript APIs allow web applications to work asynchronously, sending and retrieving data without interfering with the current user actions. Quick and responsive applications can be built with JavaScript since JS code runs on user`s browser locally.

2.3. JavaScript and a web browser as a visualization platform

JavaScript is a dynamic language, which is mainly used to modify the displayed document content in web browsers. JavaScript can change HTML DOM (the Document Object Model) elements, attributes and styles. JavaScript includes an *eval* function that can execute statements at run-time [Richards et al., 2010].

JavaScript has a powerful object literal notation (JSON) since objects can be created easily by listing their components. As JSON object is in text format, it can be easily read. Additionally, it is language independent [Crockford, 2008], allowing data to be read and used by different programming languages.

In addition to dynamic objects and expressive object literal notation, JavaScript functions are objects with lexical scoping, i.e., scope of inner function contains the scope of parent function. Lexical scoping enhances the functionality of the language since all variable definitions are accessible [Gentleman and Ihaka, 2000].

As it can be complex to support all different web browser requirements, there are many JavaScript libraries available for easier development. Although JavaScript frameworks have common characteristics like DOM manipulation, every framework has different main functionality. For instance, jQuery, one of the most commonly used libraries in websites [SimilarTech, 2014], uses CSS selectors to manipulate HTML elements, whereas D3 is a JavaScript library that manipulates documents based on data by providing powerful visualization components.

2.3.1. Reference Model and JavaScript

Card et al.'s [1999] Data Reference Model is important for understanding and applying JavaScript properties for visualizing the data. Figure 2.6 represents the modified version of the Reference Model for information visualization with JavaScript.

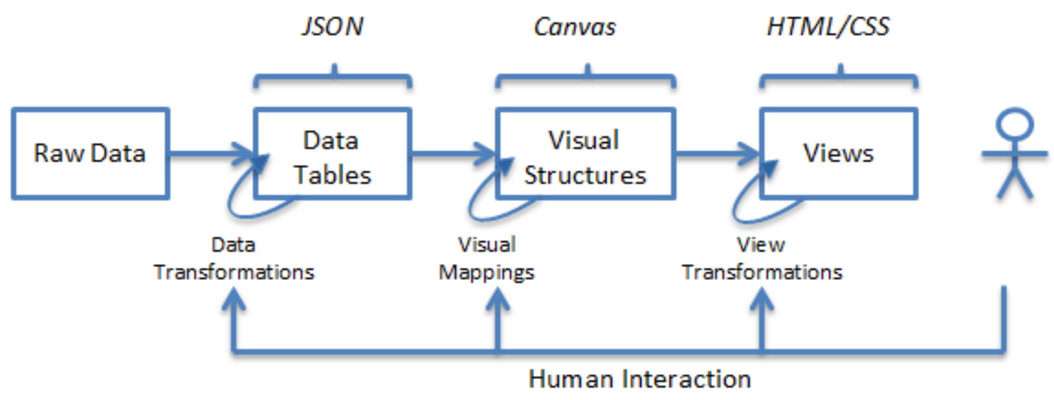


Figure 2.6 Reference model adapted for JS web visualization [Card et al., 1999].

JSON corresponds to the data table as it lists the attributes of the metadata. Visual structures, such as a pie chart, are the visualization means that are interpreted directly by the human. Canvas element of HTML5 is being used to draw elements on webpage. View transformations interactively modify visual structures to create interactive visualizations (e.g., zooming and fish eye view). Views are created with HTML elements that are formatted with CSS.

Reference model describes the approximate steps in the information visualization process. Information visualization reference model can be applied easily to the visualizations with JavaScript. JavaScript includes dedicated structures, such as JSON, SVG, Canvas, and HTML, which fit into data tables, visual structures and views of the model.

2.3.2. Interaction and Animation

Spence [2007] defines the interaction between human and computer as the heart of modern information visualization. Usually core of the data is so large that one single view is unlikely to lead to gaining insight. Interactive exploration is required so that the view triggers an `a ha!´ moment.

JavaScript provides an excellent interaction support in web browsers. Client-side JS frameworks can be utilized to enhance dynamic behaviours such as interaction and animation. For instance, interactive SVG bar charts with smooth transitions and user interaction can be generated with the various JavaScript frameworks (e.g., D3.js).

2.3.3. Compatibility and Accessibility

Web visualizations are being viewed in browsers from different ages and from different vendors such as Google and Opera. It can be a challenging task to create JS visualizations that behaves as intended in different kinds of browsers. Flanagan [2011] suggests the usage of additional libraries to deal with the incompatibility problems.

In addition to compatibility issues, it is important to provide accessible visualizations to users. Device-independent events should be supported rather than device-dependent events (e.g., mouse over) to be able to include the users regardless of which device they are using (e.g., keyboard, mouse).

2.3.4. Client-side Frameworks

Client-side frameworks build a higher-level API on top of the standard APIs offered by web browsers. JavaScript code needs to be written to use the APIs defined by the selected framework [Flanagan, 2011]. A well-written framework addresses the compatibility and accessibility issues described in the previous section. One of the main benefits of using a framework is extended functionality with less coding.

There are many JavaScript frameworks for information visualization. Some of the most widely used open-source frameworks include:

- *Processing.js:* This framework is JS port of the Processing programming language designed for visualizing the web. It converts the written Processing code into JavaScript and executes. This module makes use of the HTML5 canvas element to render 2D and 3D visualizations. The Processing API includes various methods such as canvas and color manipulation, shapes and image drawing, and math functions. [Fry and Reas, 2014]

- *Raphaël.js:* This library provides an API for SVG manipulation. This is used mostly for drawing vector graphics on web. Additionally, this API tries to solve the compatibility issues with old-versions of Internet Explorer using VML (Vector Markup Language). Websites like Washington Post and the Times Online makes use of this framework because of the compatibility advantages. [Dmitry, 2014]

- *Protovis:* Bostock and Heer [2009] created Protovis JS library to generate SVG graphics. In Protovis, visualizations are designed as hierarchy of marks such as bars and dots. Inheritance, scales and layouts are allowed in Protovis. However, it has limitations to provide animation and transitions. Therefore, Heer and Bostock developed a successor to Protovis, D3.js, to provide an improved support for animation and interaction.

- *D3.js:* Data-driven Documents (D3) is a JS library for direct manipulation of a native representation [Bostock et al., 2011]. Main purpose of D3 is to create highly interactive and responsive data visualizations by allowing animation. D3 JavaScript library makes use of the SVG, HTML5 and CSS standards to create visualizations for modern web browsers.

There are different JavaScript libraries for making the development of JavaScript-based applications easier. Every JavaScript framework has specified functionality such as DOM manipulation, GUI development, graphics and visualization development and web application related. JavaScript frameworks are beneficial in terms of dealing with the inconsistencies between runtime environments. Devoted visualization frameworks (e.g., Processing.js, D3.js) become advantageous while creating web-based applications since developers can concentrate on the visualization components.

3. D3.js: A Data-driven Visualization Framework

As described in the previous chapter, D3.js is designed to propose a novel visualization approach for web. With D3.js, designers can generate and modify web content by direct manipulation of the document object model. D3.js is a very powerful visualization library since it makes use of JavaScript, SVG and CSS.

3.1. Major Goals

According to Bostock et al. [2011], interactive visualizations should combine various web technologies such as HTML, CSS, JavaScript and SVG. They claim that visualization toolkits, which lack the ability of direct manipulation of the existing DOM, cannot make use of the different web technologies [Bostock et al., 2011].

Some of the earlier visualization tools, such as Protovis [Bostock and Heer, 2009], present *accessibility* and *expressiveness* drawbacks. It is difficult to learn the representation since the DOM is encapsulated in tool-specific formats. Additionally, tools that provide structured solutions do not enhance the development of new graphic solutions.

D3.js developers categorize their goals as follows, aiming to overcome the drawbacks related with the earlier visualization toolkits [Bostock et al., 2011]:

- *Compatibility:* D3.js aims to provide reusable components to improve accessibility and efficiency. Moreover, additional JS libraries can be utilized to assure backwards compatibility with older browsers.
- *Debugging:* D3.js simplifies debugging due to the JS console in developer tools. Developers can interactively debug by running JS in the browser.
- *Performance:* D3.js emphasizes transformation rather than representation. Since there is no specific format for certain visualizations (e.g., drawing a circle), developers can make use of this characteristic to improve performance, for instance, by writing pure HTML code.

Additional to the developer's goals, there are certain requirements for a web-based visualization framework. Some of these applied requirements are mentioned below [Aufreiter, 2011]:

- *Declarative language design:* D3.js adapts the properties of declarative programming. This approach has potential to improve performance with the help of higher-level abstractions. D3 *selections* allow this declarative approach.
- *Data Representation and Transformation:* In D3 there are no predefined vocabularies for graphical representations. Instead, alternative forms of graphics are built on top of CSS3, HTML5 and SVG.
- *Interaction:* Arbitrary data can be bound to DOM with the data-driven approach. Data is available to event handlers, enhancing the interaction.
- *Animation:* Instead of mapping the data into a static representation, D3 emphasizes manipulation. There is a transition operator devoted to animated transitions. CSS transitions can be also utilized for animation purposes.
- *Extensibility:* There are various external modules to allow extensibility. For instance, *geo* module can be used to transform geographic data into SVG paths without disrupting the core library.

D3.js allows great control over the final visual result with compatibility, debugging and performance benefits. Since D3.js fulfils the requirements of a web-based visualization framework mentioned by Aufreiter [2011], it can be regarded as a powerful library while creating dynamic and interactive web visualizations. It is common to encounter various web visualizations developed with D3.js in different areas such as data analytics and newspapers (e.g., The New York Times [Ashkenas et al., 2012]).

3.2. Creating a Design

Atomic function of D3.js can be regarded as the *selection* operation. Elements can be retrieved from the current document using the selection method. After relevant elements are selected, *operators* can be applied to modify content (e.g., attributes, styles, HTML). Event handlers can be used to create *interaction* whereas attributes can be changed smoothly over time to allow *animation*. Various *modules* (e.g., layouts) can be used to achieve common visualization tasks. [Bostock, 2011]

3.2.1. Selection

D3 makes use of CSS3 to select elements. There are two selection functions: *select* and *selectAll* where the former selects only the first matching element whereas the latter selects all of the matching elements. Elements can be filtered and selected according to their tags, class names, identifiers and attributes. The selector format, defined by the W3C Selectors API, is compatible with modern browsers. [Bostock et al., 2011] After selecting the elements, *operators* can be applied to manipulate attributes, styles, properties, HTML and text content of the selected element.

3.2.2. Data Operations

In D3.js, data is bound to DOM elements. D3 allows reuse by enabling users to work with different datasets without requiring additional work. D3 accepts various data types such as arrays, strings and objects. Additionally, it can handle large datasets in JSON formats or CSV files. The *data* operator is being used to bind the input data to the selected DOM nodes. Additionally, there are dedicated *enter* and *exit* selections for data binding to enable adding new nodes and removing unwanted nodes. [Bostock, 2011]

3.2.3. Interaction and Animation

D3.js focuses on manipulation rather than the static representation of the data. Therefore, this framework includes support for smooth transitions. *Event listeners* can be added to selected elements to recognize events supported by the browser (e.g., click, mouseover, submit). *Transition* applies the operations smoothly over time to allow animation. [Bostock, 2011]

3.2.4. Modules

D3.js is extensible with available optional modules. Selection and transition operations are the main required operations for a module. These prototypes can be extended by adding new methods. Additional modules can always be added to extend the functionality. For instance, *csv* module supports reading and writing comma-separated values whereas *layout* module provides various reusable visualization layouts such as tree-maps.

3.3. Example Applications

In this section, three example applications, which include D3.js during the application development, will be examined.

3.3.1. Example Study 1: Flight Analysis

Example study *NormSTAD Flight Analysis: Visualizing Air Traffic Patterns over the United States* [Ayhan et al., 2014] addresses the issue of the optimization of the air traffic. Ayhan et al. claim that air carries would benefit if air traffic is visualized. Flights can be scheduled more efficiently with the help of the interactive visualization of the air traffic patterns. Not only fuel consumption, landings and takeoffs can be optimized but also general picture of the air traffic can be monitored.

NormSTAD is an interactive web-based visualization application which empowers users to analyze flight data and make observations on time, distance, altitude and speed of the flights. This study intends to optimize air traffic by detecting trends and anomalies and performing strategic planning. NormSTAD uses data provided by the Aircraft Situation Display to Industry.

Normalized flight information is displayed on customizable line chart (see Figure 3.1). Users can customize the line chart according to airline, date and flight number. Figure 3.1 depicts the example application of NormSTAD. Outlier in red can be spotted once bottom graph is used to select the range. It can be observed from Figure 3.1 that, although red flight is closer to the destination compared to the other flights, it doesn`t arrive earlier [Ayhan et al., 2014]. Further analysis on the outlier flight can be performed to find the causes of the problem and this flight could be optimized.

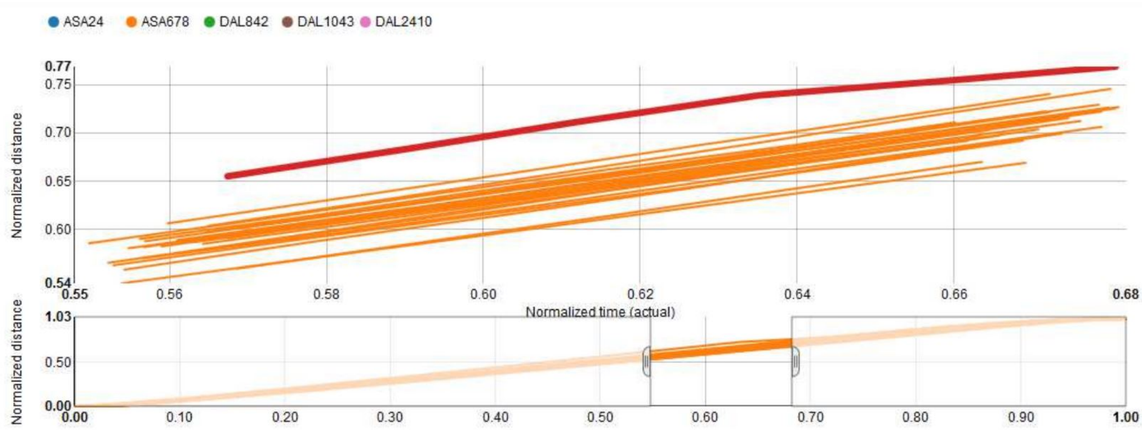


Figure 3.1 NormSTAD`s Line Chart displaying the "Distance vs. Actual flight time". [Ayhan et al., 2014]

Researchers preferred to implement web-based interface of NormSTAD with D3.js. First of all, data is imported and normalized values are stored locally using JavaScript. After importing the data, D3.js is employed to bind the imported data with the selected airlines and flights. This way visualization could be updated interactively when the selections are changed. Line charts are created with D3.js. In addition to D3.js, Google Maps API was used to provide map view of the flight routes.

Although researchers have not explicitly stated that they have conveyed the Information Seeking Mantra [Shneiderman, 1996] and Reference Model [Card et al., 1999] during the development of the visualization software, NormSTAD can be explored further regarding these frameworks.

Figure 3.2 demonstrates the application of Reference Model for the NormSTAD. Raw data is the data retrieved from the Aircraft Situation Display to Industry. After retrieving the data, researchers transformed the data into a tabular form. Line chart and map chart constitute to the major visual structures which are conceived with SVG. After applying view transformations, views are created with HTML and formatted with CSS.

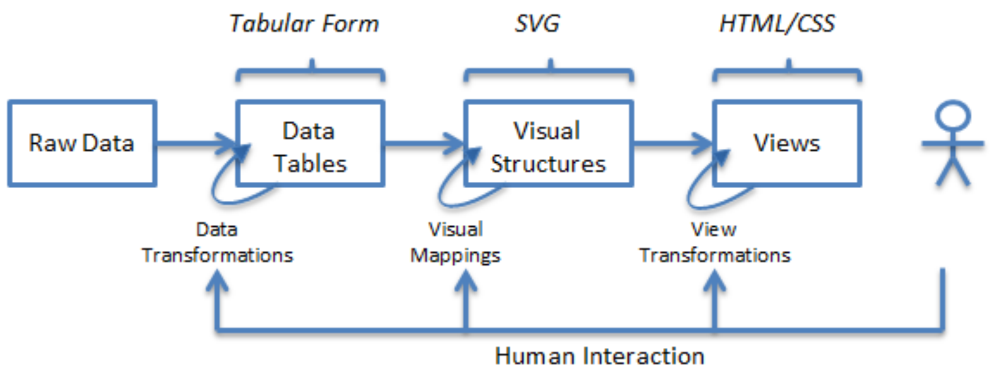


Figure 3.2 Reference model applied to the NormSTAD flight analysis tool.

Web-based information visualization tool NormSTAD can be examined further by taking Shneiderman`s Mantra into account as follows:

- *Overview:* NormSTAD provides an overview with the possible airlines and flights. General idea about the dataset can be derived from the overview.
- *Zoom and Filter:* Although zooming isn`t encouraged with NormSTAD, filtering is being extensively used. Users can limit the results appearing on the line chart by using the filters panel. Users can filter airlines, flight numbers and flight dates.
- *Details on demand:* Researchers have created separate panel for supporting details on demand. When user requires, additional information pertaining to selected flight(s) is being displayed in a tabular form.

NormSTAD is a proposed solution for optimizing the flight landings and takeoffs. Air traffic controllers can investigate flights interactively to discover flight patterns (holding, slow down etc.). Researchers applied JavaScript and D3.js to the development of the web-based visualization application. D3.js facilitated interactive line charts. Researchers separated data models, visual models, views and interaction as in the Reference Model. NormSTAD can be regarded as a successful visualization application since it conveys the principles of the Information-Seeking Mantra and allows interaction.

3.3.2. Example Study 2: Real-time Analysis of Twitter

A study called *RApID: A System for Real-time Analysis of Information Diffusion in Twitter* [Taxidou and Fischer, 2014] examines how Twitter users influence each other in real-time basis. Taxidou and Fischer developed a system called RApID to visualize the information being propagated from user to user.

Twitter maintains a social graph of followers. Information diffusion from user to user is available explicitly with the concept of retweeting. Tracing, understanding and predicting how information spreads in social media can be a challenging task. User roles like opinion leaders or spammers could be identified with the help of the understanding of the information diffusion.

RApID includes a model of information cascades where nodes correspond to the users and edges represent "who has influenced by whom". Real-time analysis of the information cascades is not a trivial task as visualization of the large and fast evolving graph is required. Updates are needed to be integrated into cascades instantaneously because of the dynamic nature of the cascading graphs. Therefore, researchers developed their own web-based visualization techniques to overcome the presentation of dynamic, large-scale cascade graphs. They have established new collapsing techniques to deal with the complex structure of the information cascades.

Taxidou and Fischer [2014] chose to visualize large and fast-evolving graph data using D3.js. User interface of RApID allows interactive visualizations of evolving cascades to provide information about how users influence each other (See Figure 3.3).

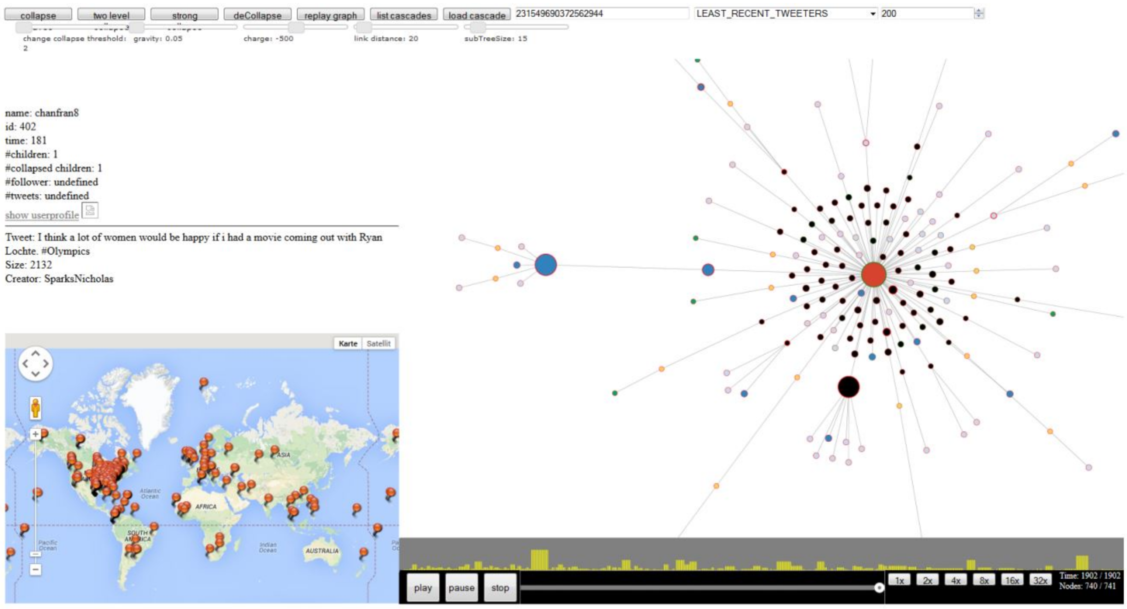


Figure 3.3 Visualization of information cascade

As Figure 3.3 depicts, visualization of information cascade includes nodes and edges. There are four complementary aspects of the illustrated visualization [Taxidou and Fischer, 2014]:

1. Dynamic representation of the evolving information cascades
2. Real-time distributions (e.g., geographical spread)
3. Relevant user information when pointed with the mouse (e.g., number of followers)
4. Information about the original tweet (e.g., number of retweets).

In order to fulfill the mentioned complementary aspects, Taxidou and Fischer [2014] developed their own web-based visualization technique of combining/collapsing leaf nodes with their parent nodes. D3.js is selected to visualize information cascades. With the help of D3.js, researchers could achieve dynamic visualizations which evolve over time with the dynamic collapsing algorithms.

Researchers kept visual Information-Seeking Mantra in mind during the design phase of RApID as they developed a system with overview first, zoom and filter, then details on demand principle. Details of how researchers complied with the mantra are described below:

- *Overview:* Detailed overview of the dataset is provided. It is possible to see the pins on the world map as tweets are being gathered. Information cascade can be played to observe the influences of users on each other.
- *Zoom and Filter:* Zooming is made available as users can select collapse threshold, link distance and sub-tree size. Additionally, users can filter the information cascades according to the collapsing techniques (e.g., full cascade, two level). With the help of these options, users can zoom and limit the displayed information through filtering.
- *Details on demand:* When the user points the mouse over a certain node, relevant user information is being displayed. User information includes, for instance, name, tweet and original creator. Users can retrieve detailed information with the interactive selection while still observing the overview.

RApID demonstrates how presentation problem of dynamic cascading graphs can be solved. Valuable insights can be gained with RApID by interacting with the dynamic and evolving cascades. RApID has proven that JavaScript and D3.js can visualize large, fast and evolving data sets with the application of Information Seeking Mantra [Shneiderman, 1996].

3.3.3. Example Study 3: Stock market visualization

Example study *Stock Lamp: An Engagement-Versatile Visualization Design* [Tanahashi and Ma, 2015] investigates the way users interact with the real-time visualizations. Although most of the design methodologies in the field of information visualization assume that users will be fully engaged in the visual exploration of the information, real-time applications do not always receive active interaction from the users. Therefore, Tanahashi and Ma [2015] have introduced new design concept called engagement-versatile design to serve the users with various engagement styles.

Tanahashi and Ma [2015] applied engagement-versatile design concept to the system called Stock Lamp to help users keep track of the stock market in real-time. First of all, they have identified different modes of engagement and derived design implications. Later on, they have applied these modes to the Stock Lamp`s visualization design. Tanahashi and Ma [2015] have defined three types of engagement modes as follows:

- *Periphery - Passive mode:* This mode suggests that visualization isn`t in the user`s sight directly and the user doesn`t pay much attention as s/he doesn`t actively interact with the system. This kind of user prefers to glance at the data quickly to check the updates.
- *Focus - Passive mode:* Users do not engage in data interaction in this mode, although visualization is in the user`s direct sight and user focuses on the system. Users prefer gazing at the visualization and passively interact to gain information.
- *Focus - Active mode:* In this type of engagement mode, users give full attention to the visualization by interacting to explore the data. Users who prefer this type of mode intends to explore data extensively for in-depth data analysis purposes.

Stock Lamp consists of two views, lamp-view and info-view, to help part-time investors in different situations regarding their attention and participation. Either one of the views is displayed based on the user`s engagement mode. In lamp-view users can view abstract information about the stocks without seeing detailed information whereas in info-view (See Figure 3.4) detailed information with descriptions is provided to the users. [Tanahashi and Ma, 2015]

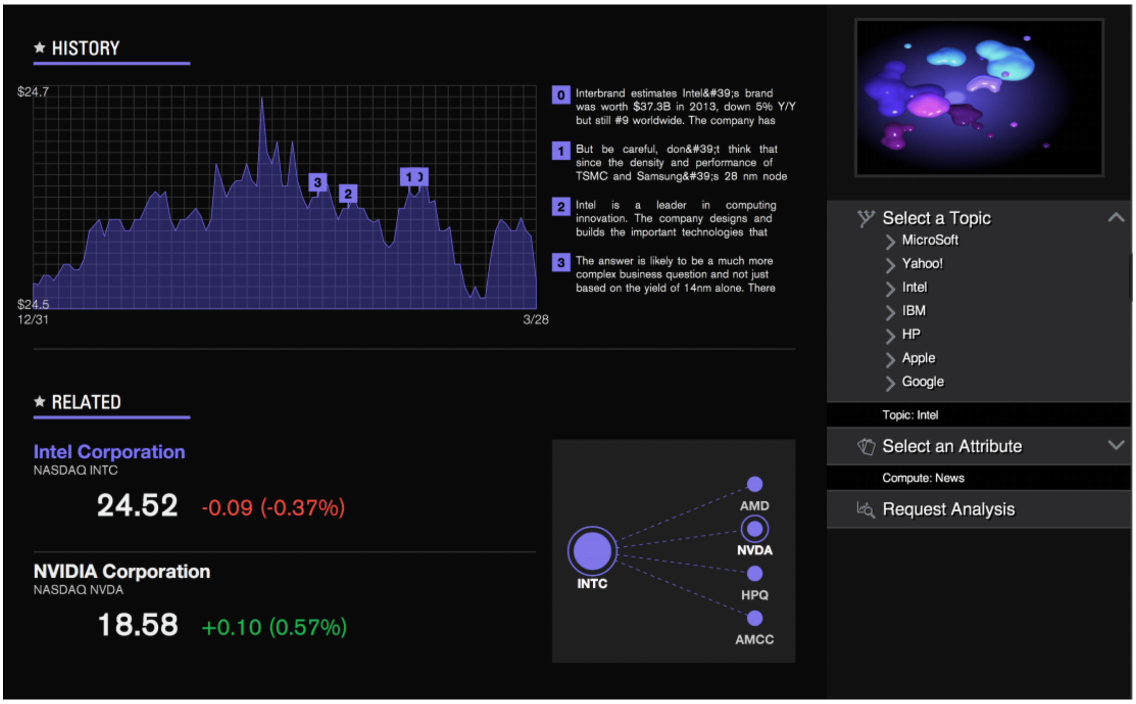


Figure 3.4 A screenshot of info-view [Tanahashi and Ma, 2015].

Researchers have used D3.js to implement the visualizations of info-view (Figure 3.4). They stated that simplicity of D3.js was the main reason for using it while developing the visualizations. With the help of D3.js, user interactions could be included and pilot users could test the interactions based on mouse and touchscreen.

Although developers of Stock Lamp mostly focused on providing different user engagement modes, it is still possible to observe the principles of the visual Information-Seeking Mantra [Shneiderman, 1996] in this manner:

- *Overview:* General information about the stocks is provided in the lamp-view. Users can understand the general picture of the stocks with the lamp-view and observe the updates on the stocks.
- *Zoom and Filter:* Users can zoom into the specific stock with the info-view. Detailed information about the selected stock is given in the overview of the info-view. It is possible to see history of the stock and related stocks. However, filtering isn`t supported in Stock Lamp.
- *Details on demand:* After selecting the specific stock in info-view, users can demand additional details such as news or Twitter feed about the stock.

Researchers of Stock Lamp present a new design concept, engagement-versatile design, to target the users with different engagement styles. According to Tanahashi and Ma, users do not always pay attention or actively interact with the visualizations in real life. First, Tanahashi and Ma present taxonomy of user engagement with traditional visualizations and determine the unique characteristics of each engagement style. Later, they use this knowledge in Stock Lamp, where investors with different engagement styles can keep track of the stock market in real time. D3.js is utilized for generating info-view as D3.js has broad built-in library for managing user interactions with visual elements. [Tanahashi and Ma, 2015] Visualizations comply with the visual Information-Seeking Mantra [Shneiderman, 1996] while serving the users with different attention and participation modes.

4. Visualization of the Publication Data

Although there are various JavaScript toolkits available for information visualization, it is still common to encounter traditional visualizations in web pages. In this thesis, visualization of the web-based publication data is developed with D3.js library in order to demonstrate the strength of JavaScript in web browsers.

4.1. User Requirements

Currently, publication data of the Tampere Unit for Computer-Human Interaction (TAUCHI) is listed as shown in Figure 4.1. Users can select from the publication years to overview the articles published during the selected year. Although users can reach to the articles directly with the provided URL links, it is not possible to gain insight or make comparisons about the overall publication information with this kind of visualization approach.

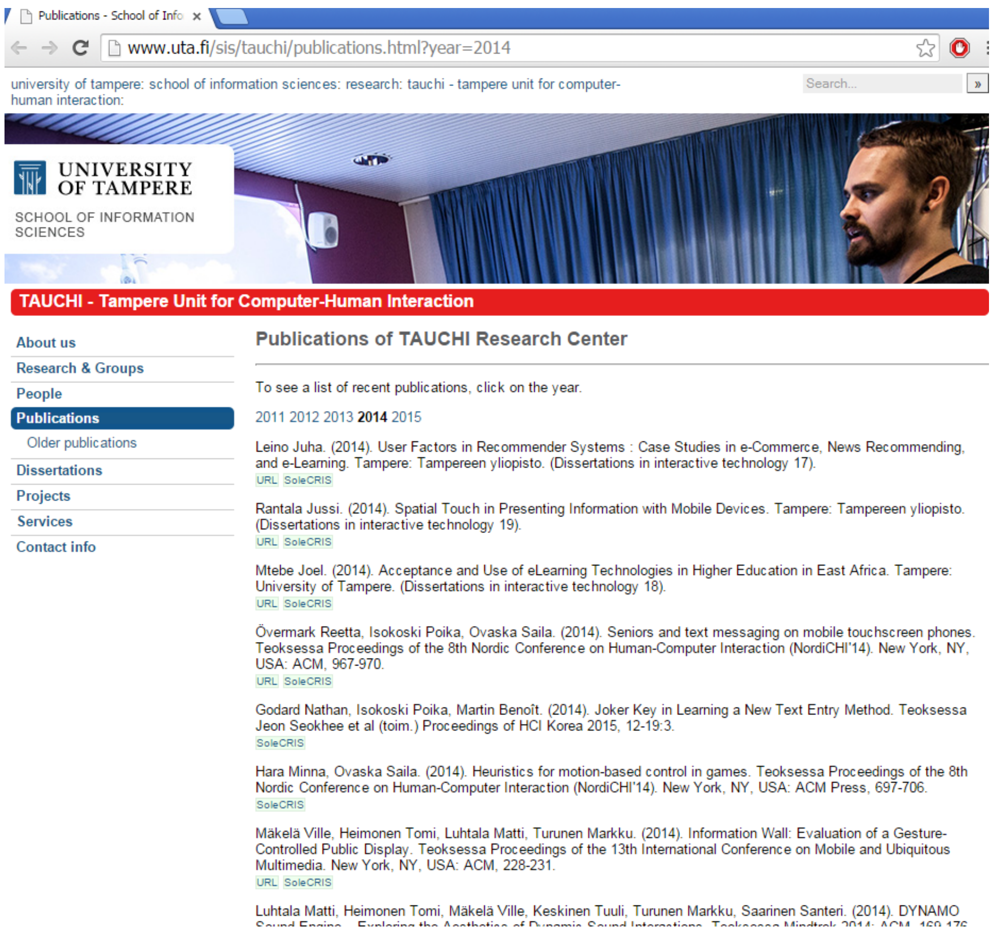


Figure 4.1 Current way of visualizing the publication data of TAUCHI Research Center.

Major user requirements when observing the visualization of the TAUCHI's publication data can be listed as follows:

1. Users should be able to observe the number of publications made every year and make comparisons between the publication years.
2. Users should be able to observe the list of the researchers who publish articles in TAUCHI research center.
3. Users should be able to observe which researcher makes the most publications.
4. Users should be able to make comparisons between the researchers.
5. Users should be able to observe the number of publications every researcher published during the year span (e.g., 2011 to 2015).
6. Users should be able to observe which topics were the most popular in overall publications.
7. Users should be able to observe which topics were the most popular during the selected year.
8. Users should be able to observe which researcher is specialized in which area.

Once the mentioned requirements are fulfilled, users can gain insight about the publication data and different aspects of the web-based publication data could be unveiled.

4.2. Related Work

Keshif is a D3.js based visual data browser, which aims at data exploration with data filtering and discovery [Yalcin, 2014]. Users of Keshif can easily filter and preview the results with a mouse over interaction. Yalcin [2014] claims that Keshif provides scalable visualizations even for big data collections. Keshif is able to load the data in a flexible manner. Structured data can be easily loaded from Google spread sheets and CSV files without requiring to hassle with coding and importing the data to JavaScript. However, for JSON objects users need to write their own importers.

Yalcin [2014] visualized University of Maryland's publication data as in Figure 4.2 in order to demonstrate the usage of Keshif. He manually entered the publication data into the Google spread sheet format. The spread sheet form has six tabs: publications, authors, keywords (e.g., education), venues (e.g., CHI, INTERACT), venue types (e.g., article, book, and thesis) and author types (e.g., student, researcher).

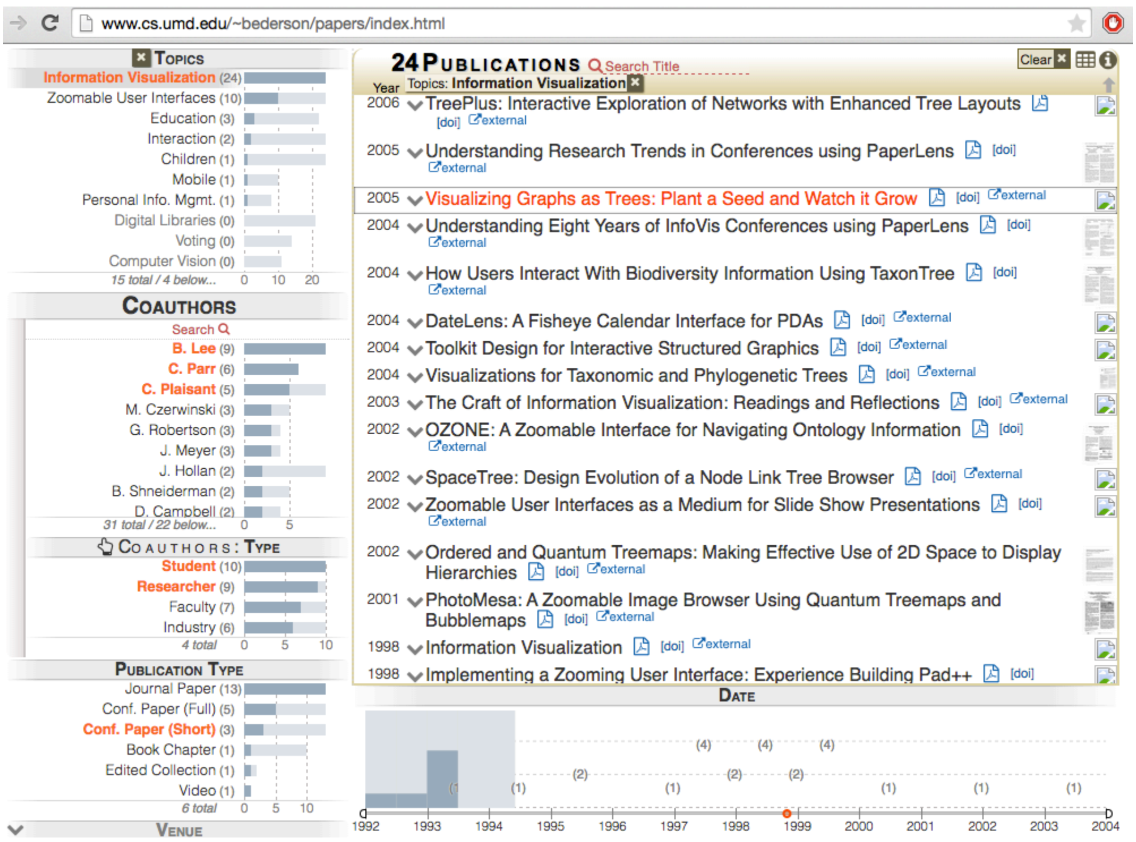


Figure 4.2 An example of Keshif with Google spread sheet based publication data [Yalcin, 2014].

Shneiderman`s Information-Seeking Mantra [Shneiderman, 1996] is applied to Keshif to create a powerful visualization tool as follows:

- *Overview:* Users can overview publications, topics, coauthors, publication types and date. It is possible to grasp knowledge about the mostly mentioned topics or during which year the most publications are made with the overview.
- *Zoom and Filter:* Users can focus on one particular area or filter information according to their interests. Users can filter publications according to topic,

coauthor, publication type, venue and date. All of the charts in Keshif allow filtering. Once a filter is selected, visualization animates smoothly.

- *Details on demand:* Users can retrieve detailed information about publications. External links are provided to reach the full publication content.
- *Relate:* Users can relate publications with topics, coauthors, publication types and date by selecting an attribute. For instance, when the user selects the topic HCI, all of the related researchers can be discovered.

Keshif provides successful visualization techniques for visualizing the publication data with the help of the application of Shneiderman`s Information-Seeking Mantra [1996]. Developers can enter data manually to Google Spread Sheets and create visualizations with Keshif. Although Yalcin [2014] presents an effortless visualization platform for the developers, this kind of visualization requires developers to structure data manually. Keshif brings a powerful approach to create quick and easy visualizations. However, additional coding is required for big data sets since it is not feasible to enter data to the spreadsheet form manually.

4.3. Implementation

Implementation of the development of the interactive charts aims to satisfy the user requirements mentioned in Section 4.1. Implementation part of this thesis consists of three major segments: getting the data from web, parsing the data and creating the visualizations. In this section, issues encountered during the achievement of the mentioned segments will be explained.

4.3.1. External JavaScript Libraries

In order to visualize the TAUCHI`s publication data, different JavaScript frameworks are used for different purposes. Pure JavaScript is used to parse the data. Additional to the JavaScript, jQuery is exploited to retrieve the data from the previous years. Visualizations such as bar chart and researchers list are derived with D3.js. In addition to JavaScript and D3.js, an additional D3 layout cloud library enabled the creation of word cloud visualization. This way, the principle of separation of concerns is enhanced.

Usage areas of jQuery, D3.js and D3 layout cloud in the implementation process are explained in detail below:

- **jQuery.js:** jQuery is a cross-platform JavaScript library especially designed to simplify client-side programming assignments. Implementation tasks such as HTML/DOM manipulation and event handling can be easily accomplished with jQuery. Many lines of JavaScript code are wrapped in a single line of code in jQuery, empowering simplicity for the developers.

  During the implementation part, jQuery is utilized to make Ajax, i.e., asynchronous JS and XML, calls. Web applications can send and retrieve data from the server without interfering with the behaviour of the current page with Ajax calls. With the help of the jQuery, publication data from the previous years could be retrieved.

- **D3.js:** D3 is used to visualize the publication data. Bar chart and researcher list are created with D3.js library. Bar chart represents the number of publications published per year whereas researcher list demonstrates how many publications every researcher has done during the year span. These visualizations are explained in detail in Chapter 5.

- **D3.layout.cloud.js:** World cloud generator is an additional JavaScript library built on top of D3 developed by Davies [2014]. This library allows words to be replaced in a word cloud randomly. Original algorithm places all of the given words into the word cloud with a random font size assignment.

  The main intention for creating a word cloud is to give an overall idea about the topics mentioned in the publications. Users should be able to observe which keywords are the most frequently mentioned in overall publications. Additionally, it would be beneficial to grasp an idea about the area of interest of the researchers. Because of these reasons, original algorithm has been changed.

Rather than displaying all of the words mentioned in the titles, it is preferred to keep a counter to determine the most frequently mentioned words. This way, users could be enlightened with the necessary information.

JSON-Object `words` includes information about every word mentioned in titles and counter for the frequency of the word. Font size is enhanced according to this counter. Creation of a word cloud object can be seen in Code Segment 1.

```
var wcloud = d3.layout.cloud().size([500, 300])
.words(words.map(function(d){
     return {text: d.Item, size:
     fontSize(+d.Count)};}))
     .padding(4)
     .rotate(function(){return ~~(Math.random()*2)* 90;})
     .font("Impact")
     .fontSize(function(d) { return d.size; })
     .on("end", draw)
     .start();
```

Code Segment 1. Creation of a word cloud object

4.3.2. DOM Manipulation

HTML DOM defines HTML objects and contains HTML element properties, methods and events to access and alter the elements. JavaScript enables DOM manipulation, allowing dynamic creation of HTML pages.

DOM manipulation with JavaScript provided various flexibilities during the implementation part. Dynamic manipulation of an HTML document is achieved in the following ways:

- *Adding new HTML elements and attributes:* Button with “visualize” label is added at the end of the publication list. Place of the button is selected with D3.js. Button is created with JS DOM manipulation.

- *Creating new HTML events:* After clicking onto the visualize button, new page with the charts needs to be created. Therefore, button on-click event is created.
- *Altering the CSS styles in the page:* Once the new page is created, CSS styles need to be determined for the visualization styles. Additional ChartStyle.css file is created with the style details. This CSS file is added to the newly created page with the JS's document write function.

4.3.3. Data Abstractions

Data can be abstracted with JavaScript for data representation and manipulation. JavaScript Object Notation (JSON) makes the data easy to read for humans. After parsing the data received from server, it is saved into JSON objects in desired formats for the visualizations. Bar chart, researcher list and word cloud make use of the following JSON objects:

- *Bar chart:* Displays the total number of articles published every year to facilitate comparisons (See Figure 5.3). Bar chart is created with D3.js. JSON data linked to the chart is shown in Code Segment 2.

```
var barchartJSON =[{"Year":"2011","Total":42},
{"Year":"2012","Total":49}, {"Year":"2013","Total":60},
{"Year":"2014","Total":64}, {"Year":"2015","Total":5}]
```

Code Segment 2. Data used for creating a bar chart

- *Researcher list:* Displays all of the researcher names who published articles in the TAUCHI Research Center and number of publications every researcher published (See Figure 5.4 and 5.5). This list is created with D3.js. JSON data used for conceiving this visualization can be seen in Code Segment 3.

```
var listJSON = [{"Researcher":"Raisamo Roope", "Published":
[[2011,8], [2012,13], [2013,14], [2014,22], [2015,3]],
"Total":60}, {"Researcher": "Turunen Markku", "Published":
[[2011,5], [2012,12], [2013,17], [2014,10]], "Total":44},…]
```

Code Segment 3. Part of the dataset used for creating researcher list

- *Word cloud:* Displays the word cloud as in Figure 5.6 using the article titles. Word cloud is created with D3.layout.cloud.js. JSON data attached to the word cloud is structured as shown in Code Segment 4.

```
var wordcloudJSON = [{"Item":"pervasive","Count":2},
{"Item":"eye","Count":4}, {"Item":"tracking","Count":2},
{"Item":"mobile","Count":9}, {"Item":"eye-based","Count":1},
{"Item":"interaction","Count":9},…]
```

Code Segment 4. Part of the dataset used while creating word cloud

4.3.4. Interaction

The key feature of modern visualizations can be regarded as user interaction. Therefore, implementation process has been aiming at creating interactive charts. D3.js' capacity of creating highly interactive visualizations simplified the development process of the charts.

Bar chart and researcher list are made interactive as follows:

- *Bar chart:* When a user hovers, selection is highlighted as shown in Figure 5.3. Word cloud is updated with the selected year's most frequently mentioned words.
- *Researcher list:* When a user points the mouse over a researcher name, number of articles published by the selected researcher is displayed as in Figure 5.5. Word cloud is updated according to the topics selected researcher wrote his/her articles on.

Event handling mechanism makes the interaction possible. Common HTML events include, for instance, onchange, onclick, onmouseover and onmouseout events. Event handling attributes can be linked to HTML elements with JavaScript. Event handlers for the bar chart and researcher list include mouseover and mouseout events to enable interaction patterns described above.

5. Implementation Results: Description, Analysis and Synthesis

Implementation task was aiming to visualize TAUCHI Research Center`s publication data so that users could gain insight about different aspects of the publications with interactive data exploration. JavaScript, D3.js and external JS library were utilized to create interactive visualizations in a web browser.

5.1. Results

In order to achieve the user requirements mentioned in Section 4.1, it was necessary to place Visualize option button to the current publication web page of the TAUCHI. Once the user selects the visualize option, new tab with the visualizations opens. This newly created page can be seen in Figure 5.1. Implementation part results in three visualizations: bar chart, researcher list and word cloud.

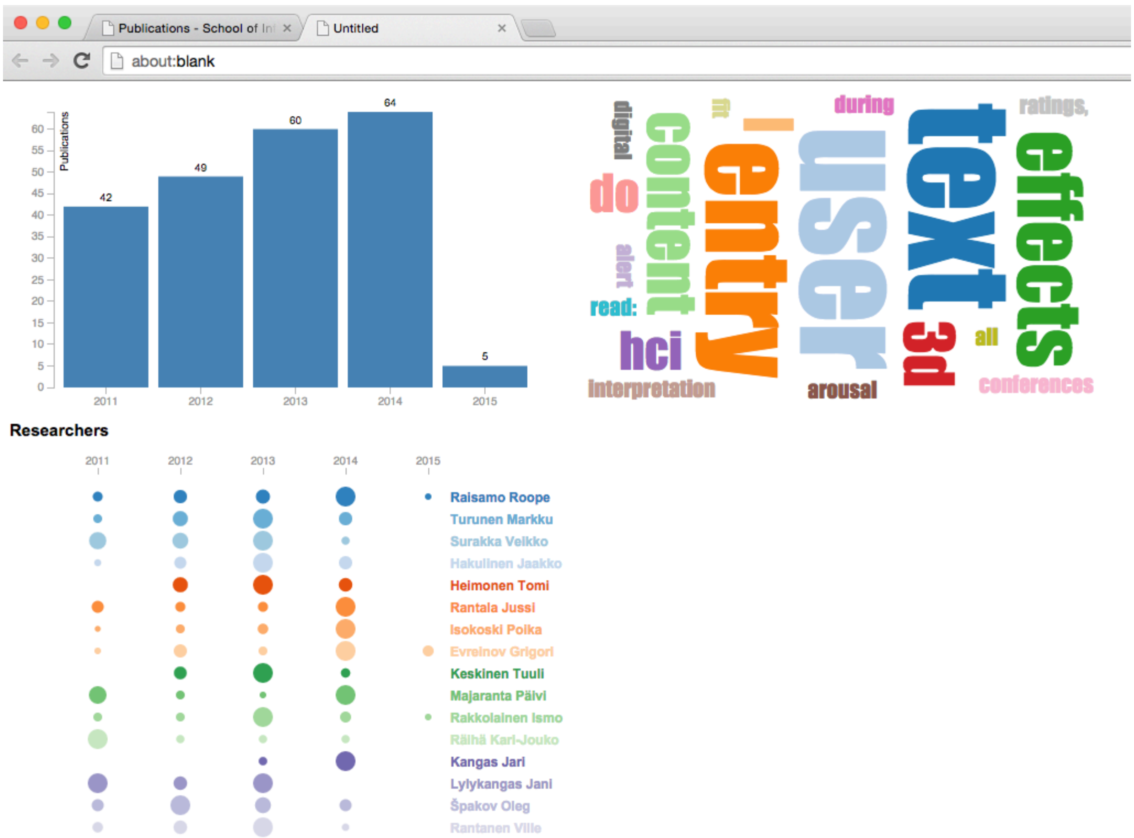


Figure 5.1 Newly created web page where bar chart, researcher list and word cloud are displayed.

Bar chart, illustrated in Figure 5.2, fulfills the first user requirement so that users can see number of articles published every year and make comparisons between the years. Exact number of publications made every year is printed on top of the every bar. Bar chart is interactive in this way: when user points the mouse over one of the bars, selected year is highlighted as depicted in Figure 5.2.

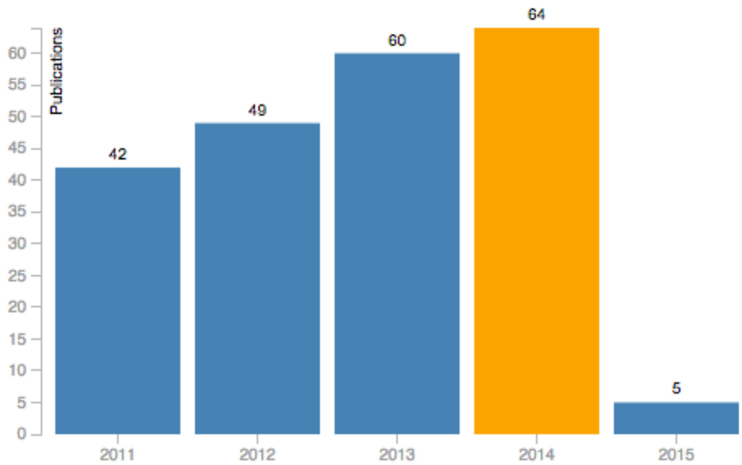


Figure 5.2 Bar chart representing the number of articles published every year.

Figure 5.3 demonstrates part of the researcher list. All the researchers who publish articles in TAUCHI Research Center are listed in this chart. Therefore, height of this chart is determined dynamically depending on the names of the researchers in the publication data.

Researchers are listed according to the total number of publications, i.e., researcher with the most publications is listed at the top. The year of the publication is marked with a circle. Circle sizes allow comparisons so that it is possible to acquire knowledge about when a researcher made most of his/her publications. Bigger circle size implies that most of the publications are made during the relative year. Circle size doesn`t allow comparisons between the researchers, instead it enables making yearly comparisons for a selected researcher.

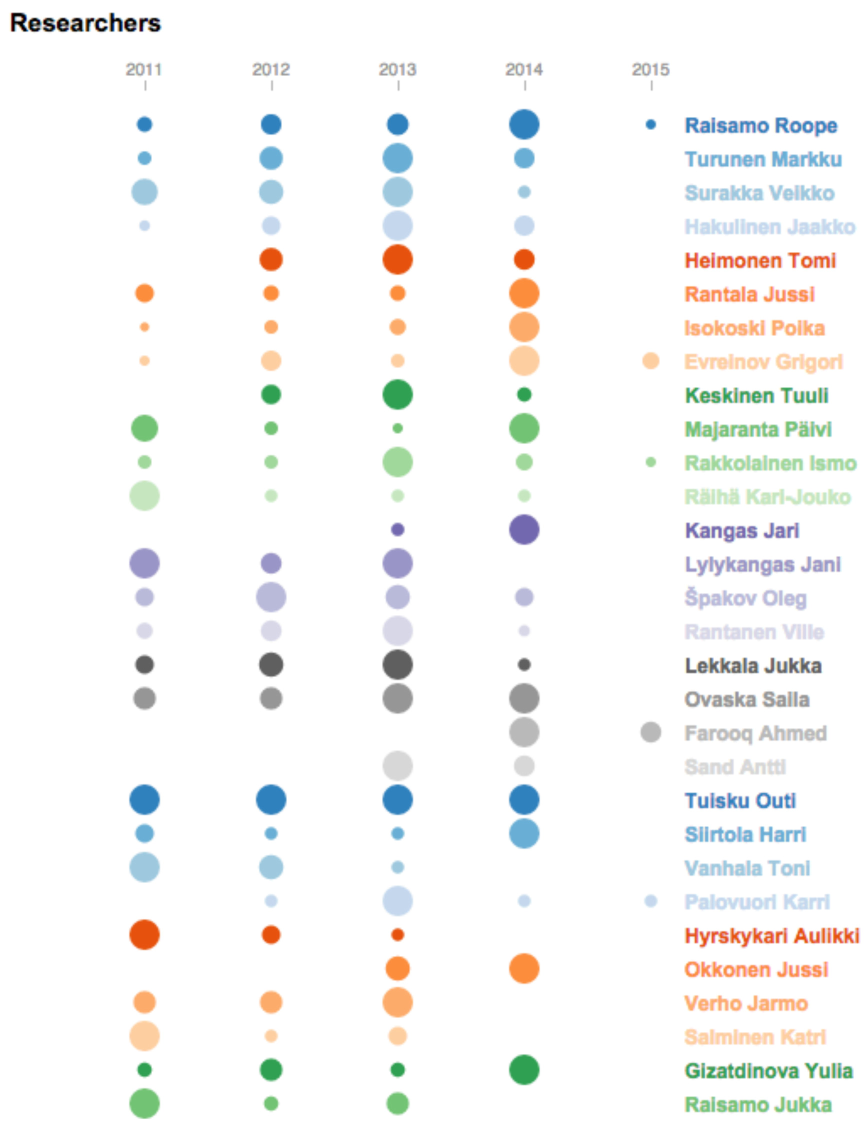


Figure 5.3 List of the researchers who publish articles in TAUCHI. (A part of the researchers is displayed in this figure).

Researcher list is also interactive. Users can observe the number of articles a researcher has published by pointing the mouse over the name of the researcher. For instance, when user points the mouse over “Raisamo Roope”, the number of articles he has published for every year is displayed as in Figure 5.4.

Figure 5.4 Interactive researcher list depicting the mouse over action.

Word cloud (Figure 5.5) includes information about the frequency of the words mentioned in all of the titles of the publications. External D3.layout.cloud.js library has handled the representation of the words in a random order. In other words, word cloud has different content or layout of the words every time it loads.

When the page loads, mostly mentioned words in the overall publications are displayed as in Figure 5.5. Frequency of a word in overall publication tittles is counted. Font size of the word in the word cloud is directly proportional with the frequency of the word.

Figure 5.5 Word cloud generated when the page loads. By default it represents the most mentioned words in overall years in a random order.

Although word cloud itself is not interactive, bar chart and researcher list can dynamically modify the word cloud content. As it can be seen in Figure 5.6, users can modify word cloud content by moving mouse over one of the years. In this case, word cloud is filled with the most frequently mentioned words during the selected year. When the user does not select a year, word cloud is updated with the most frequently mentioned words in overall years (Figure 5.5).

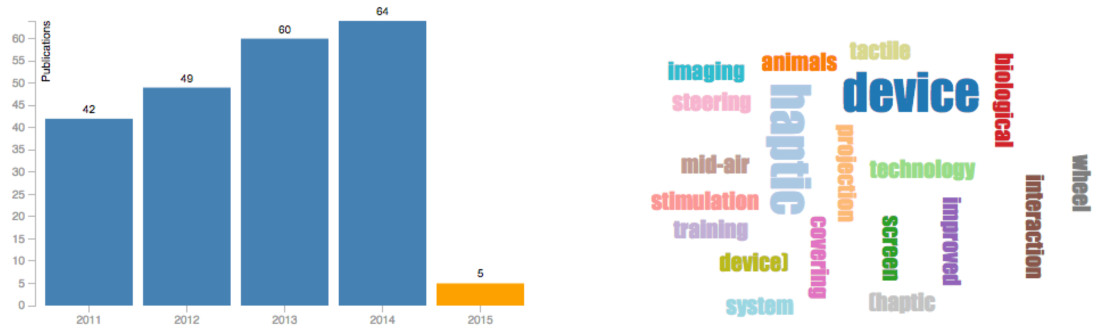


Figure 5.6 Modifying word cloud content with bar chart.

Figure 5.7 is derived as an example to demonstrate how researcher list updates word cloud. After pointing mouse over *Harri Siirtola*, the supervisor of this thesis, word cloud is filled with his most frequently mentioned publication titles. The main aim for this interaction is to let user get a glimpse about in which area the selected researcher is specialized.

Figure 5.7 Updated word cloud content when the user points mouse over researcher *Harri Siirtola*.

With the help of the newly created visualizations, users can learn about different aspects of the data. JavaScript and additional JavaScript libraries helped the creation of highly interactive and modern visualizations. Instead of displaying the publication data as a list, interactive charts are preferred to enhance users' cognitive learning processes and unveil the hidden aspects of the publication data.

5.2. Discussion

Visualization of the TAUCHI`s publication data provides an overview to the users so that users can learn more about the data and view certain aspects of the data without losing the overall context. Users can familiarize themselves with the dataset and gain knowledge with the help of the exploratory data analysis.

Shneiderman`s Information Seeking Mantra [1996] makes exploratory data analysis possible with overview, zoom and filter and details on demand functionalities. Resulting visualizations conveys to the Shneiderman`s Mantra as explained in below:

- *Overview:* Overview serves as an entry point to allow further inquiries to take place on the dataset. The resulting visualization in Figure 5.1, not only displays the number of articles published every year, but also lists the researchers who publish articles in the TAUCHI Research Center.

Additionally, it is also possible to learn about the most frequently mentioned words in overall articles.

- *Zoom and Filter:* Users might request to focus on their area of interest. Some portion of the dataset is displayed to the user with filtering. Zooming and filtering enhances data exploration by revealing additional information about the dataset. The resulting visualizations allow zooming and filtering since availability of these options is crucial for interactive data visualizations. As in Figures 5.4 and 5.6, users can zoom and filter with the help of the bar chart and researcher list.
- *Details on demand:* Users can discover about the details of the selected researcher. Although Shneiderman [1996] suggests providing details with a pop-up window, modern visualisations don`t use pop-up menus as often. Therefore, details about the selected researcher are provided with mouse over action and word cloud is updated with the details of the researcher, as shown in Figures 5.4 and 5.5.

Card et al.`s [1999] reference model for information visualization has worked as a guideline during the implementation part. Figure 5.8 represents the application of reference model to the implementation of the visualization process. Data models, visual models and interactive controls are separated from each other for creating extensible and reusable software architecture. Publication data which is available on the TAUCHI`s publications web page corresponds to the raw data in Card et al.`s model. Metadata is stored in data tables, which consist of JSON objects in this implementation case. Visual structures are created and elements are drawn with SVG on the web page. Additionally, views are created with HTML elements and styled with CSS.

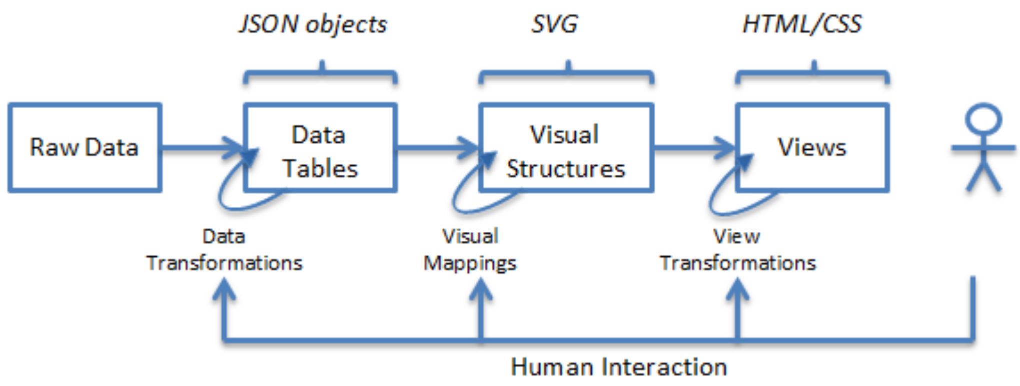


Figure 5.8 Application of the Reference Model [Card et al., 1999] to the implementation of the visualization process.

Currently TAUCHI`s publication data is being displayed textually. Although it is possible to see, for example, every article published during the certain year and article authors, modern visualization techniques in web browsers could be applied to the publication data. With the help of JavaScript and additional visualization libraries, different aspects of information could be revealed.

Resulting visualizations provide new insight about the dataset and brings new opportunities to users to explore data. User requirements mentioned in Section 4.1 could be fulfilled by applying modern visualization tools for web browsers. Unlike the previous publication data representation, users can inspect the number of articles published every year. Detailed list of researchers are also provided so that users can further investigate these researchers` publications and their area of interests. It is also possible to acquire knowledge about the most frequently mentioned words for selected year, researcher or in overall. Users can overview, zoom and filter and retrieve details on demand while exploring the publication data.

6. Conclusions

In the course of this thesis, issues for visualizing web-based applications using JavaScript have been addressed. TAUCHI Research Center`s publication data has visualized in order to demonstrate JavaScript`s strength for web-based visualizations.

Shneiderman [1996] proposed Information Visualization Mantra to achieve powerful visualizations with overview first, zoom and filter, then details on demand principle. His mantra has been frequently used and applied to the modern web-based visualization examples. Therefore, Shneiderman`s Mantra has administered to the visualization of the TAUCHI`s publication data.

As interaction between human and computer is the heart of modern visualizations [Spence, 2007], interactivity was of utmost importance while visualizing the publication data. Developed charts, namely bar chart and researcher list, enhance data exploration by allowing user interaction. Unlike the current way of displaying the publication data, users can observe different aspects of the data interactively. For instance, users can select a researcher and grasp an idea about the selected researcher`s area of interests interactively.

D3.js has been chosen as the framework while developing the interactive charts. Main reasons for selecting D3.js as the visualization framework include direct DOM manipulation, data abstractions and interaction. Visualization tasks were accomplished by employing the DOM interface directly. Additionally, data abstractions with JSON objects not only led to having reusable charts, but also enabled the application of the Reference Model [Card et al., 1999].

After introducing the main principles and concepts of information visualization, this thesis explains web-based tools for visualizing the data. Secondly, it introduces D3.js framework for web-based applications and demonstrates the example cases where D3.js is utilized for visualizing web-based datasets. Finally, it administers the mentioned characteristics of D3.js to the application of web-based data visualization. These results can be used as a guideline when selecting the appropriate tools and theories for visualizing information on World Wide Web.

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