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Towards General and Comprehensive Definition of Visualization and Visualization Pipeline

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Abstract: Recent lively advances in information technology, specifically in internet, social networks and big data have highlighted the increasing importance in the field of visualization. The role of visualization as an important mechanism for visualizing and analyzing multidimensional big data is more vital now. Despite, the agreement on its importance in various fields, the concept of visualization and visualization pipeline need to be defined clearly. In this study, we survey a collection of definitions of visualization each of which sees the visualization from different perspectives and then, we propose set of guidelines that help in defining visualization. In addition, we survey set of visualization pipelines to make the definition of visualization more practical and we also propose a list of guidelines to improve the process of creating visualization pipelines. Lastly, we listed different taxonomies of interaction techniques and then we mapped the interaction techniques to the stages that suit them in the visualization pipeline.

Key words: Data visualization, interaction, interaction techniques, visualization, visualization definition, visualization pipelines

INTRODUCTION

Now a days, the gathering and collecting of data is easier than ever because of the massive use of data sources such as computers and sensors. Moreover, the availability of tools, internet and storage played big role in this explosion of data gathering. These huge advances of data management must be combined with a very important question. How can we maximize our understanding of the collected data? In other words, how can we convert this data into information? Visualization is one of the options that are trying to help in answering this question.

Visualization existed before the invention of computers as a way to represent information visually in order to ease the perceiving process. In the era of big data and the huge increase of datasets in addition to the increase of the available storage, visualization is gaining more importance. The data produced is massive and it is hard for human to understand and analyze this data directly.

Visualization is the process of representing the data in a visual form. Visual forms are very appropriate for human especially when we know that our vision is the highest band width data path comparing to other senses. Johnson *et al.* (2007) through visualization, we can recognize relationships, behaviors, trends, outliers and connection. Images can be easily recognized and scanned and we can identify many visual properties such as color, size, volume and movement.

One of the most important characteristics about visualization is that we don't need to decode them symbolically as we do with digits and characters but we perceive them directly which makes this process of visualization is more efficient for us as humans Brodbeck *et al.* (2009).

The visualization concept has gained more and more importance in different fields because of the recent rapid advances in information technology. The growth of social networks leads to huge explosion of data that need to be analyzed, understood and visualized. Big data is introducing bigger challenges and at the same time, it reveals the truth about the importance and the need of visualization.

The need of understanding of them meaning and the goal of visualization is increasing as the need and value of the visualization is increasing (Wijk, 2005). In this study, we survey a collection of definitions that are used to define the term of visualization ad we try to give more general definition that help in understanding the concept of visualization and tries to reveal the most important pillars that any visualization must be built on. Moreover, we list set of visualization pipelines that are concerned with visual analytics. In each pipeline model, we discuss

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the descriptions and the properties of each pipeline and survey what perspectives that are covered by each pipeline.

Visualization frameworks, tools and pipelines must take care of interaction between visualization and user. In this study, we reflect the taxonomy of interaction techniques proposed by Yi *et al.* (2007) on the pipeline proposed by Card *et al.* (1999) to show the importance of interaction in different stages of the pipeline.

Visualization concept: Human vision system can accept large amount of visual signals quickly and more important it can process them in parallel. These properties of human eye make visualization very effective tool for increasing the understanding, cognition and the analysis effectiveness.

The digital era has increased the amount of information saved in retrieved not only in the level of governmental institutions or business organizations but also in the personal level. The huge growth of social networks and the massive flow of data introduce complex situations and bigger challenges. These advances in information technology increased the criticality of appropriate flexible visualizations in order to deal with this amount of information. Visualization can be seen from different point of views. In literature, we can find many definitions of visualization each of which is concerned and concentrate in one or more sides of the visualization process. For the sake of giving a comprehensive definition of visualization that takes all the perspectives into consideration, we will survey set of definitions and then present set of guidelines for establishing visualization.

Visualization definitions: One of the most popular visualization definition is the one presented by Card *et al.* (1999). It presents the visualization as a computer representation to increase the human cognition. Some early definitions define visualization as a computing method to transform symbolic into geometry for the sake of giving ability to researchers to observe the simulation of computation. Visualization is a way to see what is unseen (Bruce *et al*., 1987). The visualization is a method to render information graphically, so that the researchers can assimilate this information quickly (Friedhoff, 1990).

Ribarsky and Foley (1994) defined visualization as a mapping process from data a perceived representation. Gee *et al.* (2005) in their definition show visualization as graphical representation used to show the structure of the information and to fast the process of accessing large data sets. They highlight the importance of computer based interaction of visualization.

Owen has spotlighted the nature of data to be graphically presented and the high dimensionality of it (Fig. 1). Liu *et al.* (2014) focus on the role of 0 interaction. Wang *et al.* (2016) shows the visualization from different perspectives. It connects the visualization with human vision and cognition.

Table 1 lists the researcher and the definition for set of selected definitions of visualization.

Table 1: Visulization definations

Researchers	Visualization definition	Basis of the definition
Bruce *et al.* (1987)	Visualization is a computing method to transform data from symbolic form into geometric. It shows the researchers the result of their simulation and computation. The purpose of visualization is to enrich the discovery process and to see the unseen	Graphics Mapping Computer based systems Understanding
Haber and McNabb (1990)	The using of computer technology as a tool for understanding the collected data through simulation or measurements. This process includes the integration of different scientific fields like image processing, computer graphics, CAD, perceptual psychology and the user interface principles	Mapping Multi disciplines Understanding Computer based systems
Friedhoff (1990)	Higher volumes of data are streaming out of simulations, supercomputers and scientific instruments. This huge amount of data must be read by researchers. Instead of reading it as vast numeric matrices the use of graphical representation will ease the process and speed up the analysis rate	Visual Understanding and cognition High dimensional data
Ribarsky and Foley (1994)	The definition of visualization is the mapping of data to a representation that can be quickly perceived. The binding types can be visual, textual, tactile, etc	Mapping Quickly perceive
Tufte and Moelle (1997)	The complicated ideas can be represented easily, clearly and efficiently through the use of graphical representation. This graphical representation is the visualization and it can be understood and interpreted efficiently	Graphical representation High dimensional Understanding
Card *et al.* (1999)	Computer-based, interactive visual representation of data aiming to amplify the user cognition	Visual tool-computer based Inter action cognition
Plaisant (2005)	Visual representation and user interface to manipulate huge number of elements and to allow user to discover unseen things, take decisions or make explanation about patterns (such as clusters, trends, outliers, ...) or items	Graphical representation Large amount of data Understanding
Chan (2006)	Visualization is the use of computer-support graphical interactive visual representation of abstract data to amplify the cognition of human. It allows the user to discover the expected and the unexpected information and explore different perspectives of data	Visual Mapping Tool-computer based Interaction Cognition interpretation

Table 1: Continue

Researchers	Visualization definition	Basis of the definition
Owen (Silic and Basic, 2010)	Visualization is a tool to transform complex multidimensional datasets into images and to interpret images data that is fed to the computer	Graphical Tool-computer based High dimensional data Mapping
Khan and Khan (2011)	Visualization is about making the user understand and interpret large and complex sets of data easily	High dimensional data Understanding Interpreting
Liu *et al*. (2014)	Information visualization is the study of transforming data and knowledge into interactive visual representations	Visual Mapping Interaction
Wang *et al*. (2016)	Visualization can be seen from the perspective of human system of vision as a way for analysts to increase the ability of understanding, interpreting and exploring datasets. Visualizations dependon the visual channels to represent and transform datasets into different visual representations	Visual Mapping Understanding Cognition and vision Interpreting

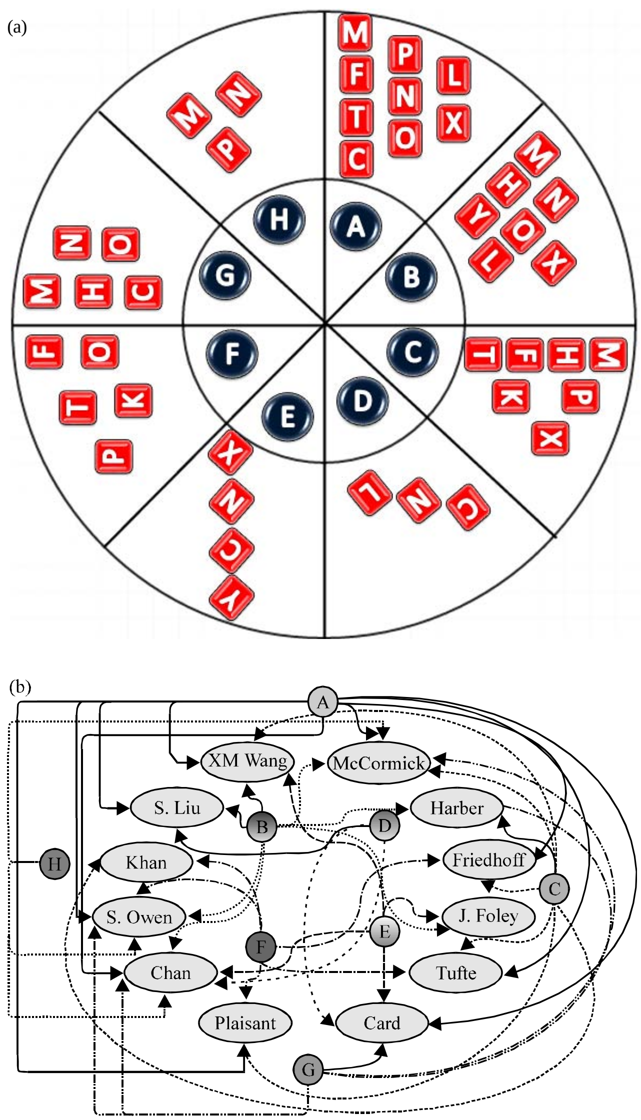

Fig. 1: Mapping of guidelines and definitions: a) Zone view M: McCormick, H: Harber, F: Friedhoff, Y: Foley, T: Tufte, C: Card, P: Plaisant, N: Chan, O: S. Owen, K: Khan, L: S. Liu, X: XM Wang and b) SemiEllipse view

Visualization definition guidelines: As we have seen, there are many definitions, each of which concerns with some properties looking at visualization from different angles and multiple perspectives. After analysis performed in the on the definitions of visualization listed in the study, we propose the following guidelines to increase the understanding and coverage of the visualization term and definition:

- A way in which data can be represented visually using graphics, computer vision, user interface
- A way to map data into a representation such as convert numeric values into geometric plane
- A way in which understanding of the user is increased
- An interactive environment
- A way that is guided by the cognition of human and by the human vision system
- A way that we can use to deal with huge amounts of data (high dimensional complex data)
- Usually connected to a tool or computer-based systems
- A way that the user can use to make discoveries, decisions or explanations about patterns such as trends, clusters, outliers, relationships

The list of guidelines presents the most important pillars of visualization. This list can be used a guidance for anyone wants a detailed definition of visualization term. The guidelines give a comprehensive look at various perspectives of visualization. Figure 1 shows the relationship between the guidelines and the definitions in two different visualizations. Figure 1a is a zone graph that gives a zone for each guideline. In each zone there is a division for the definitions that take care of this point of view. The inner circle contains the guidelines and the outer circle lists the definitions that took care of this point of view. The zone graph is easy, simple and intuitive. On the other hand, it gives limited information and we had to use abbreviations to express the name of the definition researcher. Figure 1b uses semiellipse view to represent the same information but with more details. The semi ellipse graph shows the researchers names and the guidelines letters as nodes. If the guideline point of view is taking into account by the researchers a directed edge is depicted between the guideline and the researchers name. The graph might look a little bet cluttered but it shows a complete view of the relationship. In the next study, we will add researcher level of clarity by discussing the visualization through visualization pipelines.

MATERIALS AND METHODS

Visualization pipeline: Visualization pipelines are the most popular abstraction of visualization used today by applications. Visualization can be seen as a pipeline that transforms data into graphical representation that can be perceived and interpreted by human vision and cognition systems. The visualization pipeline process starts with data capturing and then ends with a transformation of the data into the required representation. Brodbeck *et al*. (2009) illustrates the stages that are required for the process of transforming data into visual representation (Moreland, 2013).

Visualization pipeline facilitate the visual analytic process which combines analytical methods with human interaction to help in reasoning and decision making.

In this study, we will survey collection of pipelines and list the properties of each one in order to reach a common general and comprehensive description of visualization pipeline. The understanding of visualization pipeline increases the usability and the benefits of visualization.

Conventional visualization pipeline: A conventional visual analytics pipeline presented by Keim *et al*. (2010) as shown in Fig. 2. This pipeline consists of four stages with set of relationships between them.

This model starts with raw data and followed by a preprocessing stage, this stage which may consist of several steps is important to correct the errors and to reveal redundancies as well as transforming the data into the form that suits the analyst. Many different techniques can be used in this stage such as data integration, data cleaning, data transformation and data reduction. The next step is the generating and selecting of models through visual exploration and analysis that are supported by data mining methods. The visualization module in Fig. 2 allows the analyst to select, modify and evaluate the models either by modifying parameters or changing models. The purpose of feedback returning arrow is to give the analyst the ability to change the preprocessing stage methods in order to carry the whole process again and again. This model gives an abstract overview of the visual analytic process (Wang *et al*., 2016).

Data state model: Data state model proposed by Chi and Riedl (1998). It consists of four stages and there is an interaction between these stages. In this model, there is actually two parts connected by the visualization transformation. The data space is the first part and is

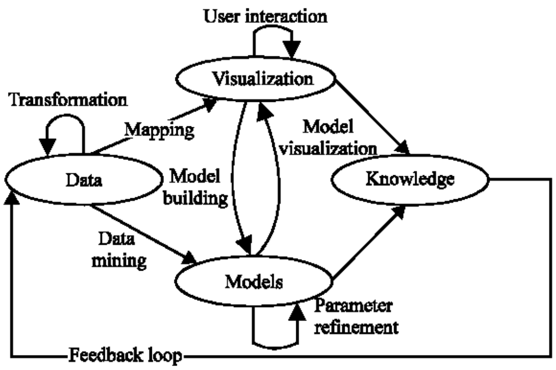

Fig. 2: Visual analytics pipeline by Keim *et al.* (2010)

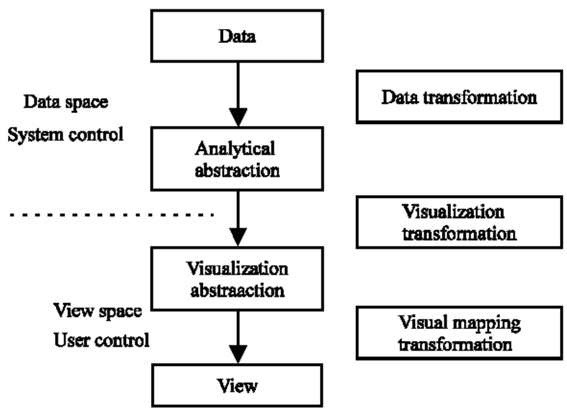

Fig. 3: Information visualization data state reference model (Chi and Riedl, 1998)

Table 2: The four stages of the model

Stages	Descriptions
Value	The raw data
Analytical abstraction	Data about data or information meta-data
Visualization abstraction	Information that is visualized on the screen using a visualization technique
View	The result of visualization mapping where the user captures and interprets the picture presented to him/her

controlled by the system and the second part which is controlled by the user is the view space part. We can see the separation of the two parts by a dashed line (Chi, 2000) (Fig. 3).

There are set of properties of this model. In this model, the steps between stages are considered as transformations. Moreover there is a clear separation between what is controlled by the system and the user control (Table 2).

Reference model: The pipeline proposed by Card *et al.* (1999) also divides the pipeline into two parts: the data part and the visual form part. Figure 4 shows the structure

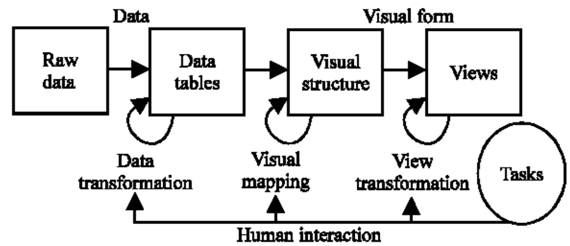

Fig. 4: Pipeline proposed by Card *et al.* (1999)

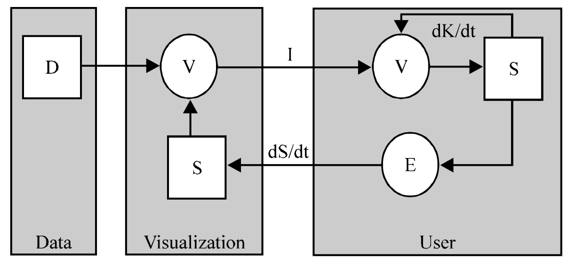

Fig. 5: Generic visualization model (Wijk, 2005); D: Data, V: Visualization, S: Specification, P: Perception and cognition, K: Knowledge, E: Exploration and I: Image, Animation

of the pipeline. The main difference between this model and data reference model is that this model highlights the human interaction.

The first step in the model presented by Card *et al.* (1999) is to transform data into well-organized data form. Many techniques can be applied in these stages. The second step is the main stage of the process which transforms the data into visual form. The last step is to display views and giving abilities such as navigation. The main difference between this model and the previous one is that in pipeline presented here, the user can interact with all stages of the visualization process.

Generic visualization model: Generic visualization model proposed by Wijk (2005). It has a precise description using mathematical notations. The pipeline has two circulations one for the input of visualization and the other for the output. Figure 5 shows the generic model where boxes represent containers and circles represent processes that transform inputs into outputs. We can notice two circulations in the model. The first one $P \rightarrow K \rightarrow P$ emphasizes the knowledge accumulation. The second circulation $V \rightarrow P \rightarrow K \rightarrow E \rightarrow S \rightarrow V$ represents the human interaction.

The data D is processed and transformed depending on the Specification S which will lead to an Image I that might be varying in time. The user perceives the image with an increase in the knowledge. The perception and cognition of the user P, the knowledge K and the image itself are the factors that affect the amount of knowledge gained.

In this model, the concentration is on the role of human and the purpose of the visualization. It depends in the way the human perceived the data and the amount of knowledge he/she has.

Nested model: The nested model presented by Munzner (2009) is different than the other pipelines mentioned previously in that it begins by discriminate between the domain and data characteristics, then it maps the output of the first stage into data types and operation abstract design. The third stage is efining interaction techniques (Fig. 6).

The main drawback of this model is that the error in uppers stages cascades to the downstream levels. Perfect encoding and interactions techniques will not be beneficial if poor decisions were made at the upper stages. This model starts from domain knowledge rather than data. It is a problem driven approach.

The visual expression process: In this model introduced by Rodrigues *et al*. (2015), the researchers presented the pipeline taking into account the relationships among visualization, cognition and vision. The model is consisted of four stages: pre-attentive stimuli, analytical perceptions, abstract patterns and decision support (Fig. 7).

Through, attentive selections the user specified some parts of the visual form and then a step of analytical perceptions is used for pattern matching to convert the perceptions into abstract patterns. The result is the target for cognition and decision making process.

The main characteristic in this model is the explicit compilation of cognition, vision and visualization process. In this study, we presented a collection of visualization pipeline models. Each model focuses attentions on some of the parts of visualization. In order to make the visualization and visualization pipeline all-inclusive, we propose set of guidelines to be followed by visualization pipeline model.

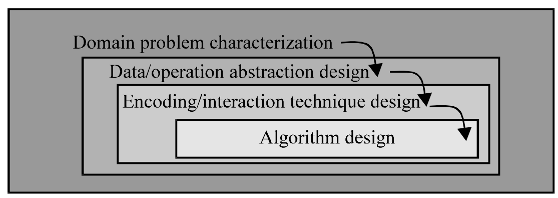

Fig. 6: Nested model (Munzner, 2009)

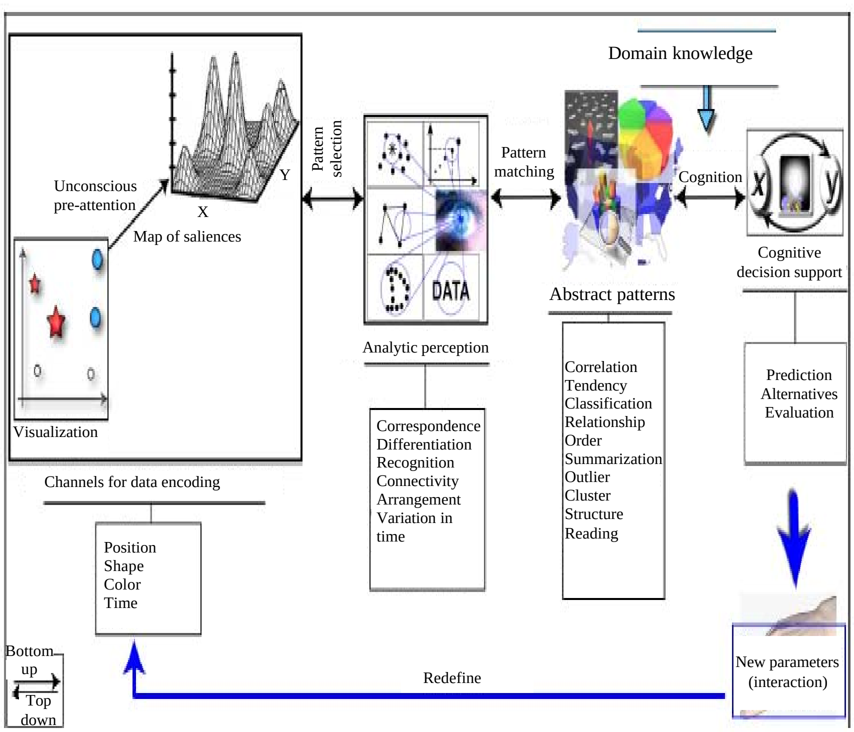

Fig. 7: The visual expression process (Rodrigues *et al*., 2015)

Visualization pipeline development guidelines: Visualization researches attempt to determine the components, stages boundaries and the relationships between data, user and visual forms. We saw that some researchers presented abstract model without drilling down into details (Card *et al*., 1999). Others presented precise mathematical definition of the pipeline (Wijk, 2005) while others explicitly related the visualization to human vision and cognition (Rodrigues *et al*., 2015). Depending on the discussion of different pipelines in the previous study, we are proposing the following guidelines that any visualization framework should pay attention to:

- Visualization pipeline should exploit the tight relationship between visualization, vision and cognition
- The stages of the pipeline must be clearly distinguished
- Visualization pipeline must facilitate the role of the user

In the stimuli phase, the user uses the channels of data encoding to produce map of saliences which gives different importance to the objects in the visual representation:

- The separation of system control and user control must be clear
- Visualization pipeline should ease the interaction between the user and the system in all of its stages
- Visualization pipeline must take care of the domain knowledge and activates the support of the knowledge
- Visualization pipeline should support annotations

By following the above guidelines we expect that the visualization pipeline will enhance the process of visualization and increase the usage of visualization.

The following study shows the connection between visualization pipelines and the interaction techniques.

RESULTS AND DISCUSSION

Interaction: The visualization interaction is the process that allows the computer to interact to the input from user. The interaction plays a very important role in visualization. It is the engine of the visualization. Without interaction the visualization is just a static graphical representation. The engagement between interaction and visualization allows the user to explore, see and understand large volume of data at once (Thomas and Cook 2006).

Table 3: Interaction techniques classification

Researchers	Classification
Cockburn *et al.* (2009)	Overview+detail; zooming, focus+context and cue-based techniques
Shneiderman (1996)	Overview, zoom, filter, details-on-demand, relate, history and extract
Buja *et al.* (1996)	Projection, aspect ratio, zoom, pan, choice of [variable, order, scale, scale aspect ratio, animation and 3-D] rotation, brushing as conditioning, sectioning, database query, scatter plot matrix, conditional plot
Keim (2002)	Iconic displays, stacked displays, dynamic projections, interactive filtering, geometrically-transformed displays, interactive zooming, interactive distortion, interactive linking and brushing
Wilkinson (2006)	Filtering, navigating, manipulating, brushing and linking, animating, rotating, transforming
Yi *et al.* (2007)	Seven different categories of interaction techniques based on user intents: select, explore, reconfigure, encode, abstract/elaborate, filter and connect
Liu *et al.* (2014)	WIMP and post-WIMP
Roth (2013)	Taxonomy of cartographic interaction primitives with four dimensions, goal; (procure, predict and prescribe; objectives; identify, compare, rank, associate and delineate; operators; import, export, save, edit and annotate, rearrange, sequence, resymbolize overlay, reproject, pan, zoom, filter, search, retrieve and calculate; operands; space-alone, attributes-in-space and ace-in-time

User interaction is the best way to enable users to generate visual forms and to transfer from a view to researchers one while managing the captured data.

Classifications: There are many interaction techniques that allow users to interact with visual representations such as charts and graphics. It allows user to drill down for details and to change the type of view (Khan and Khan, 2011).

The interaction approaches are usually classified as brushing and linking techniques, panning and zooming (zoom in and zoom out), focus-plus-context (fisheye view) and magic lenses (the galaxies view) (Hearst, 1999).

Another traditional taxonomy of interaction techniques is dividing them into four categories: overview+detail which presents multiple views at the same time, zooming which is a closer view for more details, focus+context which enlarges area within the contextual view and cue-based techniques which highlight items within the information space (Cockburn *et al*., 2009). In Table 3, we list set of different taxonomies of interaction techniques.

As listed in Table 2, we can see different classifications for interaction techniques. In this study, we selected the classification listed by Yi *et al*. (2007).

They categorized interact action techniques into seven groups. In the next study, we will map this classification into the pipeline presented by Card *et al.* (1999).

Mapping interaction techniques into pipeline stages: The interaction techniques classified by Yi *et al.* (2007) into seven categories: select, explore, reconfigure, encode, abstract/elaborate, filter and connect. The classification is based on the user intentions.

In this study, we will map the seven categories to different stages of reference pipeline model. This classification is used as a basis for interaction techniques. In addition, we will select the reference pipeline model as an example of visualization pipelines because the model is explicitly engage the user in all stages of the pipeline through interaction. The seven interaction categories are reflected on the pipeline stages as follows.

Select: Allows the user to select an item and keep track of it. Select interaction techniques can be applied in the views stage of the reference pipeline.

Explorel: Interaction techniques enable users to see different things. This technique can be applied in the data table stage and in the view stage of the reference pipeline.

Reconfigure: Interaction techniques allow users to explore different perspectives of the data sets and changing the arrangement of representations. These interaction techniques can be applied in the last two stages of the reference model, the data table and the view stages.

Encode: Interaction techniques provide users with capabilities to change the fundamental visual representation of the data such as (color and size) they are related to pre-attentive cognition and can increase the understanding of the user. These techniques can be applied to the visual representation directly in the view stage of the reference model.

Abstract/elaborate: Techniques enable users to elaborate more details such as (drill down, zooming). These techniques can be applied in the data table stage and the view stage.

Filter: Interaction techniques allow users to change the set of data items being presented based on some conditions like dynamic querying. In reference model, these techniques can be applied in the data table stage.

Connect: Interaction techniques show relationships and connections between data items. These techniques can be reflected in the view stage of the reference model.

CONCLUSION

This study is part of ongoing research in the visualization field in general. Our analysis reveals many definitions of visualization in the literature, each of which concentrates in specific perspectives. Our findings show that many visualization pipelines proposed to help in constructing appropriate visualization. This study attempts to give a comprehensive definition of the visualization by proposing set of guidelines that describe the main aspects of visualization.

Furthermore, we survey the visualization pipeline and propose set of guidelines to assist researchers in constructing visualization pipelines that meet the goals of visualization process.

Moreover, we connected interaction techniques with visualization pipeline by assigning different interaction techniques to various stages in the pipeline.

RECOMMENDATION

For a future work, the analysis can be extended to cover the visualization techniques and can be connected to interaction techniques and to visualization pipeline stages.

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