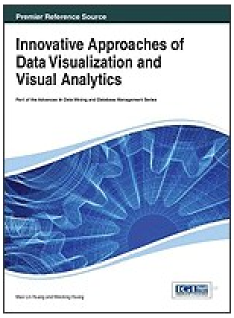

Innovative Approaches of Data Visualization and Visual Analytics

by Mao Lin Huang and Weidong Huang (eds)

Chapter 9: Highlighting in Visual Data Analytics

Mao Lin Huang

Jie Liang,
School of Software, University of Technology
Sydney, Australia

Weidong Huang,
CSIRO ICT Centre
Sydney, Australia

ABSTRACT

Highlighting has been known as a basic viewing control mechanism in computer graphics and visualization for guiding users' attention in reading diagrams, images, graphs, and digital texts. Due to the rapid development of theory and practice in information visualization and visual analytics, the role of 'highlighting' in computer graphics has been extended from just acting as a viewing control to being part of an interaction control and a visual recommendation mechanism that is important in modern information visualization and visual analytics. In this chapter, the authors present a brief literature review. They try to assign the word 'highlighting' a contemporary definition and attempt to give a formal summarization and classification of the existing and potential 'highlighting' methods that are to be applied in Information Visualization, Visual Analytics, and Knowledge Visualization. We also propose a new three-layer model of 'highlighting' and discuss the responsibilities of each layer accordingly.

1 INTRODUCTION

Highlighting scheme has been widely applied in real-world applications. Highlighting is a very popular method in computer graphics. It is commonly used to guide users' attention and to reduce the human cognitive effort in reading graphical pictures. As a new applied discipline of computer graphics, Information Visualization has inherited this method as one of the major mechanisms for the viewing control. However, as the result of rapid development in visual computing, highlighting has expanded its role in the traditional computer graphics and formed its specific meaning and functionalities in Information Visualization and Visual Analytics.

Nevertheless, existing understanding of highlighting has stopped its potential functionality and performance in visual analytics. Upon that, inevitably, there are many implementation problems existing in current practices. This research is aimed to raise the attention and emphasis on Highlighting. Highlighting seems to have a simple concept but is more complicated and useful than what we usually think. To address these challenges, we redefine highlighting and refine the theory of highlighting in information visualization and try to distinguish it as a new mechanism of reducing human cognition process for visual analytics. Therefore, we have made an attempt to provide a formal summarization, classification and to further explore evaluation of the existing Highlighting approaches and techniques to date so that its usefulness can be maximized in Information Visualization (Huang & Liang, 2010). We describe the results of this attempt in more detail in this chapter.

2 THE CONTEMPORARY DEFINITION OF HIGHLIGHTING

Highlighting was considered as one of the most common terms in computer graphics. However, the literature shows that there is little agreement on the understanding of highlighting. In non-professional fields, the interpretation of highlighting is either limited to the specific scope of color and lighting, as self evidence of its name, or broadened to be the process of emphasizing information. In the research field, there is also a debate on the definition of highlighting which varies from one domain to another.

Specifically in the domain of information visualization, Becker and Cleveland in 1987 described highlighting as brushing special color to paint the object; in 1999, Liston et al. illustrated highlighting as the process of emphasizing related sets of information, through visual annotation, within a view or across multiple views; in 2003, MacEachren et al. referred highlighting as the indication method by using transient visual effects; in 2004, Seo and Shneiderman suggested the term highlighting for the visual link across multiple views; in 2005, Ware and Borrow further defined it as an effective way with pre-attentive visual cues. Recently, Ware and Borrow discussed highlighting methods from static to dynamic approaches (2004). Nevertheless, these definitions all confined highlighting as the basic techniques for viewing only. Hence, it also implies that the understanding of highlighting in the literature of visualization still remains in the lower level as a viewing control mechanism.

However, the need in processing and understanding large and complex datasets means that further development in visual computing should go beyond the current capacity of visualization tools for exploiting the meaningful information and maximizing the human's ability of interpreting. To response to these challenges, this chapter attempts to establish the highlighting as an essential component of visual computing to offer services for visual navigation and visual analytics.

To put forward the research of highlighting for visual analytics, the first step is to re-define the highlighting. Highlighting naturally is planted in visual thinking and visual communication. Only appropriate definition of highlighting will help researchers and practitioners would be able to design appropriate visualizations for users to extract meaningful information out of the visual processing. However, there are challenges in defining highlighting. The limitation of highlighting definition has obstructed extending scope of highlighting and the understanding of terminology for both non-professional and professional fields. Hence, the primary goal of this research should be to re-define and extend highlighting, and to deliberate the changing role of highlighting from assisting view, to higher functionalities.

Therefore, we defined highlighting in three layers that each have different responsibilities and purposes:

- In traditional view-based visualization, highlighting acts as a viewing control to attract user's attention into a portion of the visualization.
- In interactive visualization, highlighting functions as a navigation control mechanism to guide users progressively reach the final target by visual interactions.
- In knowledge visualization and visual analytics, highlighting is further applied as part of artificial intelligence process to provide users with a set of graphical recommendations for the decision making.

It is worth noting that our new definition has gone beyond the limitation of traditional understanding of highlighting and moved on to the capability of speeding visual thinking and accelerating decision making performance. This profound change is intended not only to expand the boundary and fulfill the theory of highlighting, but also advance the potential development of highlighting in the future.

Therefore, the specific objectives of this study are to refine and extend highlighting, and also to elaborate on the changing roles of highlighting from merely assisting with viewing, to interacting with information, participating directly in cognitive processes and finally facilitating with decision making.

3 THE CONCEPTUAL MODEL OF HIGHLIGHTING

As an independent component of visual computing, highlighting should fundamentally be able to direct a new way to overcome the problem of information overload and reduce the process of human cognition, and at the same time meet challenges of collaborative analysis tasks. The new conceptual model we proposed consists of three layers (see Figure 1 for more details). As can been seen from this figure, the lowest layer is viewing control that is to solve the information overloading problem. The middle layer is interaction control that aims to ease the cognitive process for information seekers. The top layer is visual recommendation that mainly targets for decision makers in collaborative analysis tasks.

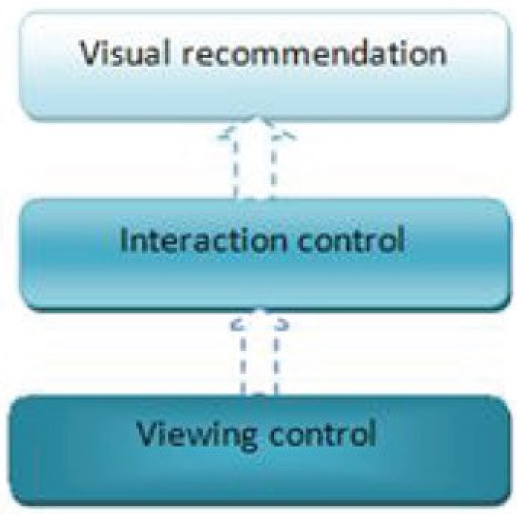

Figure 1: Conceptual model of highlighting (Huang & Liang, 2010)

3.1 Viewing Control for Information Overloading Problem

The main reason why it is used for visualization is that the highlighting method has the potential to help address information overloading and complexity of information. Due to continuous updating of the data, the visual representation of the data often generates visual clutters that add extra cognition overheads in viewing and understanding the information. Accordingly, the analysis processes have become increasingly time-consuming and complicated. Highlighting as a simple technique aims to reduce confusion, to minimize the learning curve and to increase accuracy and efficiency of humans understanding the information.

3.2 Interaction Control for Information Retrieval

When used for interactive visualization, highlighting has the capability to guide the information seeking process. Users may have difficulties in finding target or useful information since this usually involves extensive and recursive cognitive thinking. In these cases, highlighting should provide mechanisms allowing users to follow the right path and progressively reach their interested information in the most appropriate and comprehensive manner.

3.3 Visual Recommendation for Decision Making

Evaluating options and making decisions are common in visual analytics and knowledge visualization. In these situations, highlighting may be used to attract decision makers' attention to a small portion of highly relevant information and knowledge that is directly beneficial for their decision making. This will help decision makes to spend their valuable time wisely and efficiently, without being distracted to and spending time and effort in reading less or non-relevant information and knowledge.

It is true that often analysts and decision makers are different people in commercial or research communities. Therefore, it is possible that a solution to refining highlighting in one area may not be applicable in another and a new solution is required for collaborative decision making processes.

4 THE ELEMENTS OF HIGHLIGHTING

In this section, we discuss the basic elements of highlighting, from which we can implement a variety of highlighting methods. The following table gives a summarization on the elements that have or can potentially be used to design highlighting (Table 1). The elements of Highlighting is able to utilize are Size, Shape, Lighting, Motion and Presentation (Figure 2).

Table 1: The elements of highlighting (Huang & Liang, 2010)

Differentiation	visual variables	series logic
Differentiation in size	Area of object or view increase or decrease	Large/Medium/Small
Differentiation in shape	2D or 3D geometric shapes regular/irregular	Shape transformation
Differentiation in lighting	Intensity Frequency or wavelength	Light /medium /heavy weak/strong
Differentiation in motion	speed, acceleration, displacement, and time	motionless/relevant motion/absolute motion
Differentiation in presentation	style-based Line-based	Abstract/details focus/outlier/boundary

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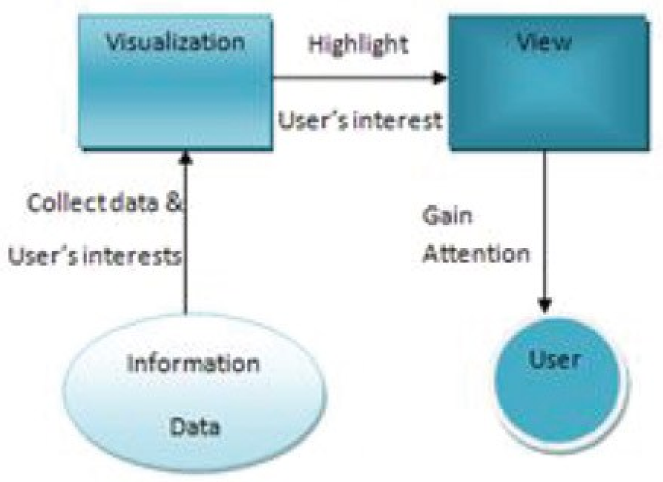

Figure 2: Illustrations of Differentiation in graphic elements (Huang & Liang, 2010) (a) Color (b) Light contrast (c) Transparency (d) Size (e) Shape (f) Presentation

As can be seen from Table 1, the "Differentiation" is essentially the key to classify and implement highlighting. For example, differentiation can be made in lighting, shape, size, motion and presentation. These elements of highlighting can be used either individually or in combination. The mechanisms of such usage can be defined below according to Robinson (2009):

Single Mechanism

In this mechanism, one highlighting method is applied upon one data object at a time. This mechanism uses a simple binary "on or off" method that is common in most visualization software.

Categorical Mechanism

Highlighting methods are applied categorically to define and classify the data objects. This highlighting method could follow a classification that has been applied to a dataset to modify the highlighting method's visual intensity accordingly. If an analyst would like to show the details of for example, the results of a clustering, or wants to reveal some uncertain properties of data and statistical significance in the visualization, this categorical mechanism can also be meaningful to apply.

Compound Mechanism

When single or categorical mechanism is not suitable or fails to adequately reduce visual complexity, this mechanism may come handy and it applies multiple highlighting methods together for the data objects, based on user's interest or specific visual requirements of the visualization. Compound highlighting may facilitate quick interpretation, using multiple elements of highlighting. Compound highlighting may be either conjunctive (same combination of highlighting methods in each view) or disjunctive (different combinations of highlighting methods in each view). Conjunctive compound combines same highlighting methods in each view, while disjunctive compound can select different combinations of highlighting methods in each view. Typical conjunction combines motion, and color.

Continuity Mechanism

This highlighting method is applied along a gradient from one value to another. This mechanism will facilitate to clarify visual transition, in below cases. First, most data attributes are changing dynamically in a continuous scale in real time application. Second, the analysts are interested to monitor the change between the data object to a target.

5 THE CLASSIFICATION OF HIGHLIGHTING

5.1 Viewing Control Layer

Viewing control process is based on pre-defined algorithms. As shown in Figure 3, the visualization defines the parts of the picture that the user is interested in and highlights the corresponding portions of the view to attract user's attention. In this layer of the highlighting, most data properties are commonly used to implement the highlighting, such as color, light, size, shape etc. We discuss these in more detail in what follows.

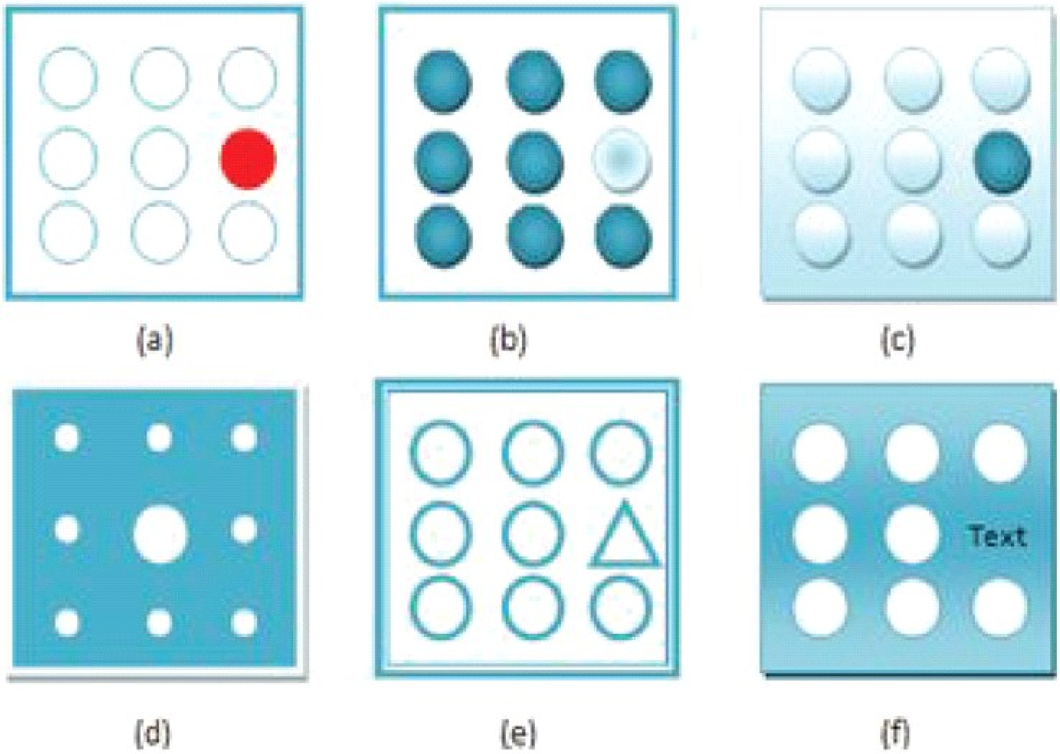

Figure 3: The framework of viewing control (Huang & Liang, 2010)

5.1.1 Differentiation in Lighting

As mentioned earlier, basic highlighting function can enhance visual features and be applied in real world applications with an efficient outcome. That is actively guiding the user's attention to the intended area of the visualization. These features are typically perceived by humans quickly and effectively (e.g. color, light, or transparency).

In general, the differentiation in lighting can be operated into one, two, three or even multiple dimensions visualizations based on different applications. Parallel coordinate visualization has successfully uses highlighting to control the viewing. It displays the focused poly-lines within a thin region. Alternatively, color and light highlighting are used to select data in specific scope of dimensions (Siirtola & KJ, 2006). XmdvTool (Martin & Ward, 1995) created by Martin and Ward progressed the function to highlight a series of data of high dimensions in a "brushed tunnel". Siirtola and Raiha further advanced this solution in a new version of parallel coordinate explorer interface (Siirtola & KJ, 2006). They rearranged data into multiple layers of highlighting by adopting differentiation in lighting.

5.1.1.1 Color

For the purpose of highlighting, a range of color groups can be displayed by a different range of spectrum. The color difference and level of de-saturation can be used to distinguish between the highlighted objects, depending on the extent to which the required details of views should be revealed in specific visualization environment. For example, in the case of growth matrix in financial data visualization(Keim et. al, 2006), by using color and color de-saturation highlighting techniques, it becomes possible to show the performance of a fund in all time intervals over a time period of 14 years (about 11.000 intervals).

To give a further example, studies have shown that different color highlighting methods can lead to different information seeking behaviors of humans (Huang et al, 2009; Huang & Huang 2010). For example, in finding shortest paths between two nodes, the user will need to look for the target nodes first if these two nodes are not highlighted. On the contrary, the user could start the path search straightaway without having to locate where the two nodes are first. This is because humans have periphery vision that allows us to see what is in the surrounding of our main focus without having to moving our eyes. As mentioned by Huang (2013), these different highlighting strategies lead to different eye movement patterns, thus different levels of task performance. This, in turn, requires different visualization techniques to use in order to support effective information visualization and visual analytics.

5.1.1.2 Contrast

Contrast also can be used to visually separate highlighted objects from background information. Modification relies on measurements or ranking to control either how sharp certain objects appear, or how much blur should apply to background information to make the highlighted objects appear more obvious. In geo-visualization, it is sometime called "Depth of field highlighting" (Robinson, 2009). For example, visualization tool of Kosara et al. adopted Semantic Depth Of Field (SDOF) method (2001) and their user studies have proved its usefulness.

5.1.1.3 Transparency

Transparency can be used as a transient highlighting technique to dissolve the context around the object of interests. The alpha level of objects can be set to render the focused object in the display, but this potential method has not been evaluated. The previous work of context and focus visualization by Huang and Nguyen (Nguyen & Huang, 2004), has proved that if transparency level is carefully selected, it can be designed to guide users in navigation as a highlighting method. While the background of structure fades, the view of "Applets" sub-structure is standing out of the whole data structure and the size of the focus view is also enlarged in the space filling presentation. Nguyen & Huang's work in layering and transparency (Nguyen & Huang, 2004) provides initial reference for further implementation, but it is still a challenge to determine the appropriate level of transparency for displays that have been colored with light-to-dark color schemes.

5.1.2 Differentiation in Size

As another powerful option for highlighting, the size-based method has been common in emphasizing difference between graphical objects. It can be used together with other methods such as color and lighting. However, it is specially applied to the situation when color or lighting based methods fail to deliver the ideal outcome, especially for color-blinds who have troubles to distinguish color and light. For example, in visualizing a social network using a node-link diagram, we can use size to represent important. Nodes with large sizes mean that they are more important. To visualize a scientific citation network, we can use size to represent times a paper is cited by other papers. The larger the node, the more times the paper is cited.

Taking the example of text annotation, the color and light variation seems to be the simplest solution for the presentation of overlapping digital annotation from different authors, but only under the strict restriction of Authors’ number. To improve the performance of the digital library query system, digital annotation (Nichols et al., 2000; Bouthors & Dedieu, 1999) and visualizing shared highlighting (Villarroel et. al, 2006), have been used in text documents and make recommendations for recommender systems. The proposed annotation Highlighting is strived to be able to compare annotation from different users and also to achieve the relevance levels which are calculated from the number of coincidence of highlighted fragments. Most work stopped in using highlighting with color and light variation. In order to achieve visualizing annotation shared and comparison mode, Villarroel et al. made notable improvement and jump out of single color style, and attempted several color groups and color contrast. However, beyond three authors, the visual annotation presentation would look like a confusing color palette with mixture of different color fragments, as overlap of annotation creates more color entries. We could hardly identify or compare the annotations from different authors in digital applications (Villarroel et. al, 2006). It is inappropriate to exclusively reply on only one property for shared annotation. In this situation, the shape of text annotation is likely another indicator to go beyond three authors for annotation comparison visualization.

5.1.3 Differentiation in Shape

Similarly, shape can be a potential method applied into existing practices as well. The Gestalt research and Geon Theory has shown that humans have a tendency to seek out the object's edges and they can quickly detect when one shape is different from another. Taking email visual organization as an instance, in order to expand details of email indicators, Bernald Kerr successfully adopt color highlighting of different scheme and finally move on to the indicator of shape (Kerr, 2003). In attribute highlighting, Kerr naturally used color de-saturation to rate the importance of emails, and employed different shapes of circle, solid circle, hollow circle to present the importance of people, to be distinguished from other attributes using light differentiation.

5.1.4 Differentiation in Presentation

5.1.4.1 Style

This method was initially used in geo-visualization (Robinson & Center, 2006). The idea of style reduction or addition is to separate and highlight different data objects in geo-visualizations. This method works especially well with visual representations that are designed with multiple graphical elements. We may change styles of some visual objects by changing, adding, deleting colors, sizes or labels of them, or other graphical elements so that the objects of the interest can stand out. To give an example, we can image a complex social network whose actors have multiple attributions such as age, gender and religion. If our task in consideration is related to age only, they we can simply remove other irrelevant attributes in the visualization without having to removing the actors completely.

5.1.4.2 Line

The line-based highlighting method is mostly used for indicating relationship between positions of data or objects, a direction path from one object to another. For example, leader lines and contouring lines (Robinson & Center, 2006) adopted from map design, also give differentiation for the object in relation to it neighborhood. Line based highlighting can also be drawn in variations of color, width, and stroke style. For example, in a single view of treemaps visualization, analysts usually have to identify several related objects, which may spread over the display.

5.1.4.3 Contouring

Contouring is also inspired by map design. This method outlines data objects and brings the effect that outlined objects are "higher" than noncontoured neighbors (Robinson & Center, 2006). In MEgraph system prototyped by Ware et al., company nodes were colored to categorize into different sectors. When users click on an object or objects, the contour of the selected node will be outlined with bright white. However, the contouring method has not yet much been adopted in prior work as a highlighting style yet.

5.2 Interaction Control Layer

In interaction control, the highlighting is applied in navigation process that guides users to progressively refine their focus views to reach the final target view. The navigation process may also be the process of data retrieval (see Figure 4). This highlighting layer may apply most elements differentiation, particularly in size of display area.

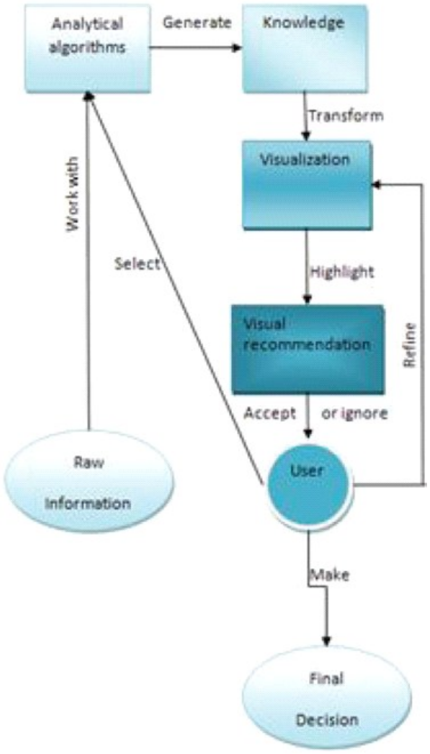

Figure 4: The framework of Interaction Control (Huang & Liang, 2010)

5.2.1 Differentiation in Size of Display Area

Most view-based highlighting takes advantage of differentiation in size and shape to provide focus and background information based on what level of details of the information should be revealed as required by users. With the support of available information, users may modify view transformation, browse and switch the data by different granularity with highlighting indications.

5.2.1.1 One View

As a special case of one view, information is often highlighted by showing only a part of it. In partially view highlighting, drilling-down + semantic zooming is a method that adopts differentiation of size and shape. This method is the most commonly used interactive navigation technique. For example, fisheye + zooming (Shi et al., 2005), power finger, and view distortion. This navigation scheme is quick and simple and has been widely established in the current operation systems, web researching and many common applications. Ben Bederson, director of the Human-Computer Interaction Lab, from University of Maryland created Fisheye Menus (Bederson, 2000) with size differentiation highlighting, for the application of linear lists. The interactive Map of Washington D.C., also applies this primary highlighting technique in order to increase size of the station "Metro centre" and transform the shape into the fish eye in the navigation.

5.2.1.2 Two Views

In coordinated views, Focus and context view is another existing method relying on element of size and shape. It provides users with a detailed view of a focused sub-graph and overall graph to maintain user orientation. Typical techniques in focus + context navigation scheme include sunburst (Stasko & Zhang, 2000), and information slices (Andrew & Heidegger, 1998).

5.2.1.3 Different Views

Merging views has also been used for highlighting. This method is adopted from "overlay" Technique in construction planning (Liston et al., 2000). This new highlighting method takes the views from different team members and integrates them into one view. To review the project, the team could focus on comparing and evaluating what is the important information on this one "merged" view. This method implements following types of overlaying actions, overlaying document to document of same type, objects to document of same type and document to document of different type and objects to document of different type by certain mechanisms.

5.2.1.4 Multiple Views

The usage of multiple views for visual highlighting has been largely unexplored in research. We have proposed a visualization method with Multi-context views. In this method, visualization with chains of full history is employed to be one of highlighting techniques in multiple views. It increases the context of an entity collection step by step and integrates the presentation of structure with the presentation of context. It was shown that multi-context view Visualization has successfully solved the conflict between the goal of providing structure and the goal of visualization detail context (Huang, Liang & Nguyen, 2009). Referring to the historical times from multiple context views, and enlarged focus views, analysts could match this significant event to the suspected trading patterns which had frequently occurred in history. As a further benefit of doing this, analysts might be able to identify the actual plans and predict the next action accordingly.

5.3 Differentiation in Motion

Motion based highlighting methods are relatively less popular compared to other main-stream ones. But they are gradually gaining popularity among researcher and professionals in recent years due to the facts that real world data are often dynamic and change all the time and that the technologies are increasingly accessible for realization of motion effects. For example, Microsoft PowerPoint elicits the method of motion highlighting in its customization of presentation slides. It has four categories, object by entrance, by exit, by emphasis, and by motion path. The entrance and exit highlighting includes show and hide function and other dynamic effects. The emphasis positioning may include spin, arrow, circular, jolt, radiating and flash or combination (Ware & Bobrow, 2004). For example, in our previous work of trading network visualization (Huang, Liang, & Nguyen, 2009), a flashing circle highlighting over a suspected focus can be further implemented to identify a suspected behavior of domination of the stock price.

In Visual thinking with an interactive diagram, Ware (Ware et al., 2008) suggested and evaluated three motion highlighting methods, Circular motion, jolt motion and crawl motion. In Circular motion, all of the nodes and links in the connected sub-graph move with a circular motion around center position, with an amplitude of approximately 2 mm and frequency of 1 Hz. Nodes and links in the selected sub-graph in Jolt motion, move in pulse using the function ampl = 0.5sin $(8.0\pi t)/(60t\times t+0.5)$ cm. In Crawl motion, the selected links show smoothly animated sawtooth pattern radiating from the selected node. The evaluation shows that in larger application with more than 300 objects, the exploration of diagram can't be discerned without highlighting.

In the motion path highlighting, the object may move in straight-line or along curve according to certain shapes. Bartram's usability study (Bartram & Ware, 2002) proved that motion highlighting is much more effective than color or shape change in signaling a change to a data glyph presented on the screen. He also further supported his assumption that motion highlighting technique is promising solution for separating a group of objects enabling a rapid visual search on the groups.

5.4 Presentation in Interaction

Differentiation in presentation can also be extended to interaction control. In real world systems, it is common to display multiple views in one platform. Analysts may constantly switch between different views, from context or variable to source file. It is normally time-consuming process. During interaction, visual link can be implemented to maintain mental navigation. The links can connect data in separate views and show relationships between them. Steinberger et al.'s technique in 2011 makes visual links standout from the surrounding base representation. They evaluation shows the technique increases the visibility of the links and minimizes the occlusion of important information (Steinberger et al., 2011).

5.4.1 Shapes in Interaction

Differentiation in shape has also used interaction control. Most of the existing Treemaps algorithms are based on axis-aligned rectangles. Hence, limiting Treemaps visualization to vertical-and-horizontal rectangles blocks the utilization of human capability in object recognition, due to the same fixed angles of the shapes in the tree visualization. Variations of angles and/or shaped nodes positively direct a way to achieve better graph perception and insight generation for focus recognition and change tracking. For example, embedding distinctive shapes in traditional rectangular Treemaps in certain division within visualization can highlight anomalies.

A new space-filling visualization method has been created which we call Angular Treemaps (Liang et al., 2012). This version of treemap is capable of laying out large relational structures whose visualization can be varied to highlight important substructures. This is achieved by using a specifically developed angular partitioning algorithm. This algorithm produces the variation and helps users to locate and identify importance of a specific piece of information or focus of interests. This technique is flexible and can be either used based on user's preference manually or applied by supporting automated analysis.

Angular treemaps can be utilized in visual representation of massive datasets in order to emphasis places of interest set by users, during the process of interaction. For example, it can highlight one focus, two focuses, or more on either the same level or different levels. In addition, angular treemaps are able to employ with multiple partition angles, to emphasis the data structure. For example, with angular treemaps, when the level of visualization goes deeper, the rotation angle decreases. This creates a sense of level change, thus being suitable for users to maintain the awareness of structure tracking (Liang et al., 2013).

5.5 Visual Recommendation

In knowledge visualization and visual analytics the role of highlighting can be further extended as part of the knowledge discovery process to provide users with a set of graphical recommendations for their decision making. In knowledge discovery, a large volume of the raw data is pre-processed by analytical algorithms, such as data mining or feature selection algorithms. These algorithms are generated by domain experts or statistical methods based on empirical or mathematical theories and are usually applied to process the data at the background. The resulting knowledge of the analysis is used for facilitating the decision making process.

However, in many cases, the textual or tabular representations of the knowledge are hard to be understood by decision makers, especially the relational structures among knowledge. Therefore, the modern visualization technologies allow decision makers to take advantages of human vision to visually interpret the knowledge. However, for a particular decision maker, he or she may only need a specific segment of the knowledge, rather than a complete set of knowledge displayed in the visualization for the decision making. Therefore, we "highlight" particular segments of the knowledge in the visualization as visual recommendations, which we believe are the most beneficial for a particular decision making process. In the process, users have choices to either accept or ignore the visual suggestions. When visual results are unsatisfied, users are allowed to refine the visualization with different highlighting mechanism. Consequently, this visual recommendation process can be iterative (See Figure 5). In brief, visual recommendation could not only suggest a shortcut for user to reach the knowledge he or she pursue for decision making, but also enhance the knowledge discovery experience for users.

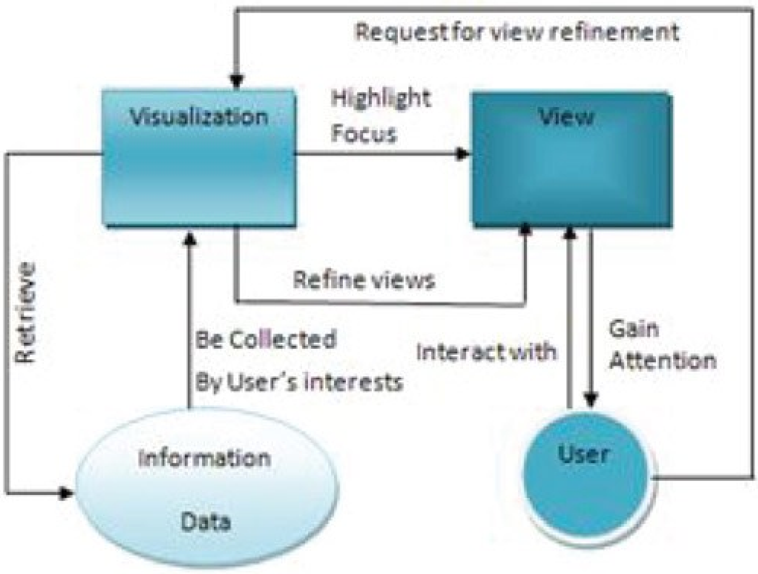

Figure 5: The framework of visual recommendation (Huang & Liang, 2010)

However, prior works mainly focused on traditional highlighting. In existing research, there is insufficient guidance for visual recommendation. Below are two rare cases which are potentially used in knowledge visualization.

5.5.1 Case One

Visual thesaurus (ThinkMap, 2008) powered by think map uses intelligence to suggest the words relating to or synonyms in a given language. Color, size and shape are used for the purpose of highlighting so that the viewing process can be facilitated. Rollover motion highlighting is also employed along with "back and forward" button, which allows users to interact and navigate in the maps of words. To assist learning the knowledge in thesaurus, the visual recommendation process is utilized. This mechanism highlights the words or the meaning of them based on system's definition of the term. As a result of this, users are enabled to act with suggestions made by the system. In this way, users can either narrow or broaden the meaning of term based on his or her own understanding and discover the knowledge. For example, if the user would like to look up the word "highlighting", then the think map could highlight suggestions within the thesaurus. In succession, the user clicked on one of the suggestions. Then the think map centralized and magnified the word "spotlight" and displayed another series of suggestions.

5.5.2 Case Two

In most situations, overloaded information hidden in complex data set visualized by traditional treemaps could exceed human cognitive ability to process. The Angular Treemap approach offers flexibility to generate different layouts when needed for emphasizing interests of focus in the hierarchy. Angular treemaps can not only be applied to emphasize difference but also highlight similarity. (Liang et al., 2012) For instance, two rotated folders attract our attention. We realized that two folders have similar layouts and same colored file types. We opened the dataset following the directory indicated by angular treemaps. We found that they are almost duplicates with slight difference. In this example, similar structure or even same structure of files contained in two rectangles with different aspect ratios are easily neglected. Angular treemaps successfully prevented the overlook (Liang et al., 2012).

6 CONCLUSION

We believe that the extension of the term of ‘highlighting’ has not been completed yet. It will be continuously refined and extended with the growth of the data volume and advances of new technologies in information visualization and visual analytics. Most designers have not yet paid enough attention to the formal explanation and systematical theories. In most cases, ‘highlighting’ is still taken for grant as the use of color and light. As a result, ‘highlighting’ has been limited to basic viewing aid in most applications.

Therefore, this chapter has attempted to define and classify the existing and potential highlighting techniques. Highlighting covers many disciplines and areas of experiences, like science of cognition, user physiology, aesthetics, human vision study, visualization and visual analytics. The strong theory base is the ground for the evolution of highlighting. To ensure highlighting as lynchpin in visualization and interaction, we should continue the theory development, extend practices of highlighting and advance the user-center evaluation for highlighting. More specifically, it will be beneficial to utilize highlighting visualization to make greater contributions and long term impacts in several aspects. First, with formal evaluation and strong evidence, we can confidently recommend satisfactory highlighting techniques for clients and partners, based on their domain requirements and nature of their data. Second, this research provides some theoretic evidence for professionals to develop more effective visualization tools, in terms of user's needs. Third, it will additionally benefit education and training curriculum development.

REFERENCES

Ahmed, A., Fu, X., Hong, S., Nguyen, Q., & Xu, K. (2009). Visual analysis of history of world cup: A dynamic network with dynamic hierarchy and geographic clustering . *Visual Information Communication*, 25-39. Berlin: Springer. doi:10.1007/978-1-4419-0312-9_2

Andrew, K., & Heidegger, H. (1998). Information slices: Visualizing and exploring large hierarchies using cascading, semi-circular discs. In *Proceedings of IEEE Symposium on Information Visualization*, 9-12. New Brunswick, NJ: IEEE Press.

Bartram, L., & Ware, C. (2002). Filtering and brushing with motion. *Information Visualization*, *1*(1), 66–79.

Becker, R., & Cleveland, W. (1987). Brushing scatterplots. *Technimetrics*, *29*(2), 127–142. doi:10.1080/00401706.1987.10488204

Bederson, B. (2000). *Fisheye menus*. New York: ACM.

Bouthors, V., & Dedieu, O. (1999). Pharos, A collaborative infrastructure for web knowledge sharing . InAbiteboul, & Vercoustre, (Eds.), *Research and Advanced Technology for Digital Libraries. Lecture Notes in Computer Science* (215-233). Berlin: Springer-Verlag, Inc. doi:10.1007/3-540-48155-9_15

Huang, M. L., Liang, F. L., Chen, Y. W., Liang, J., & Nguyen, Q. V. (2012). Clutter reduction in multi-dimensional visualization of incomplete data using sugiyama algorithm. In *Proceedings of IEEE Information Visualization Conference*, 93-99. New Brunswick, NJ: IEEE Press.

Huang, M. L., & Liang, J. (2010). Highlighting in information visualization: A survey. In *Proceedings of IEEE Information Visualization Conference,* 79-85. New Brunswick, NJ: IEEE Press.

Huang, M. L., Liang, J., & Nguyen, Q. (2009). A visualization approach for frauds detection in financial market. *IEEE Information Visualization Conference*, 197-202. New Brunswick, NJ: IEEE Press.

Huang, W. (2013). Establishing aesthetics based on human graph reading behavior: Two eye tracking studies. *Personal and Ubiquitous Computing*, *17*(1), 93–105. doi:10.1007/s00779-011-0473-2

Huang, W., Eades, P., & Hong, S.-H. (2009). A graph reading behavior: Geodesic-path tendency. In *Proceedings of the IEEE Pacific Visualization Symposium,* 137-144. Beijing: IEEE Press.

Huang, W., & Huang, M. L. (2010). Exploring the relative importance of crossing number and crossing angle. In *Proceedings of the 3rd International Symposium on Visual Information Communication*. New York: ACM Press.

Keim, D. A., Mansmann, F., Schneidewind, J., & Ziegler, H. (2006). Challenges in visual data analysis. *Information Visualization*, 9-16.

Kerr, B. (2003). Thread arcs: An email thread visualization. *Citeseer*. Retrieved from http://citeseer.uark.edu:8080/citeseerx/showciting;jsessionid=0BA75E333 AE2127F3F70223E43A73075?cid=818372.

Kosara, R. & Miksch. (2001). Semantic depth of field, *Citeseer*. Retrieved from http://citeseer.uark.edu:8080/citeseerx/viewdoc/summary; jsessionid=298F7F0386E377889ECF1B4887C50C5B?doi=10.1. 1.24.174.

Liang, J., Nguyen, Q. V., Simoff, S., & Huang, M. L. (2012). Angular treemaps–A new technique for visualizing and emphasizing hierarchical structures. In *Proceedings of IEEE Information Visualization Conference*, 74-80. New Brunswick, NJ: IEEE Press.

Liang, J., Nguyen, Q. V., Simoff, S., & Huang, M. L. (2013). Angular Treemaps . In Banissi, E. (Ed.), *Information Visualization-Techniques, Usability, & Evaluation*. Cambride, UK: Cambridge Scholar Publishing.

MacEachren, A., & Hardisty, . (2003). Supporting visual analysis of federal geospatial statistics. *Communications of the ACM*, *46*(1), 60. doi:10.1145/602421.602452

Martin, A., & Ward, M. (1995). High dimensional brushing for interactive exploration of multivariate data. In *Proceedings of the 6th Annual Conference on Visualization.* New Brunswick, NJ: IEEE Computer Society.

Nguyen, Q. V., & Huang, M. L. (2004). A focus+context visualization technique using semi-transparency. In *Proceedings of the Fourth International Conference on Computer and information Technology*, 101-108. New Brunswick, NJ: IEEE Press.

Nichols, D., Pemberton, D., Dalhoumi, S., Larouk, O., Belisle, C., & Twidale, M. (2000). DEBORA: Developing an interface to support collaboration in a digital library. In *Proceedings of European Conference on Digital Libraries*, 239-248. Lisbon, Portugal: ECDL Press.

Plumlee, M., & Ware, C. (2006). Zooming versus multiple window interfaces: Cognitive costs of visual comparisons. *ACM Transactions on Computer-Human Interaction*, *13*(2), 209. doi:10.1145/1165734.1165736

RINA Systems, Inc. (n.d.). Retrieved from http://www.rinafinancial.com/.

Robinson, A. (2009). Visual highlighting methods for geovisualization. *Citeseer*. Retrieved from http://citeseerx.ist.psu.edu/inde.

Robinson, A., & Center, G. (2006). Highlighting techniques to support geovisualization. *Citeseer*. Retrieved from http://citeseer.uark.edu:8080/citeseerx/viewdoc/summary; jsessionid=C7399B91D98763433F13B57449C2AC90?doi=10.1. 1.79.757.

Seo, J., & Shneiderman, B. (2005). A rank-by-feature framework for interactive exploration of multidimensional data. *Information Visualization*, *4*(2), 96–113. doi:10.1057/palgrave.ivs.9500091

Shi, K., Irani, P., & Li, B. (2005). An evaluation of content browsing techniques for hierarchical space-filling visualizations. In *Proceedings of IEEE Symposium on Information Visualization*, 81-88. New Brunswick, NJ: IEEE Press.

Siirtola, H. & K. J. R. (2006). Interacting with parallel coordinates. *Interacting with Computers*, *18*(6), 1278–1309. doi:10.1016/j.intcom.2006.03.006

Stasko, J., & Zhang, E. (2000). Focus + contest display and navigation techniques for enhancing radial, space-filling hierarchy visualizations. In *Proceedings of IEEE Symposium on Information Visualization*, 57. New Brunswick, NJ: IEEE.

Steinberger, M., Waldner, M., Streit, M., Lex, A., & Schmalstieg, D. (2011). Context–Preserving visual links. *IEEE Transactions on Visualization and Computer Graphics*, *17*(12), 2249–2258. doi:10.1109/TVCG.2011.183

ThinkMap Visual Thesaurus. (n.d.). Retrieved from http://www.visualthesaurus.com/.

Villarroel, M. (2006). Visualizing shared highlighting annotations. *HCI Related Papers of Interaction,* (195).

Ware, C., & Bobrow, R. (2004). Motion to support rapid interactive queries on node-link diagrams. *ACM Transactions on Applied Perception*, *1*(1), 3–18. doi:10.1145/1008722.1008724

Ware, C., & Bobrow, R. (2005). Supporting visual queries on medium-sized node-link diagrams . *Information Visualization*, *4*(1), 49–58. doi:10.1057/palgrave.ivs.9500090

Ware, C., & Gilman, A. (2008). *Visual thinking with an interactive diagram*. Berlin: Springer.

Washington D.C. Interactive Map. (n.d.). Retrieved from http://www.cs.umd.edu/class/fall2002/cmsc838s/tichi/ fisheye.html.