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A Survey of 3D Document Corpus Visualization

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Abstract: This study proposes a survey on it mainly around 2 functions units in the visualization pipeline: spatial layout and interaction. For the former, 4 layout styles (node-link, cluster, virtual widget and miscellaneous) and 2 augmentation types (focus+context, photo-realistic rendering) are introduced and, for the latter, 4 interaction styles of (3D walkthrough, filter, specification placement and annotation) and 2 augmentation types (multimedia and animation) are also suggested. In addition, 7 application areas are also provided to present some interesting findings study and future directions.

Key words: Document corpus visualization, 3D spatial layout, interaction, survey

INTRODUCTION

The report of Lyman and Varian (2003) shows there are huge quantities of documents existing today. How to effectively visualize those documents with 1 dimension (1D), 2 dimensions (2D) or 3 dimensions (3D) layout is a challenging problem. 3D can display more information with more flexibilities than 1D or 2D if the 3 dimensions are properly utilized and in recent years, there are a lot of studies on 3D design for document corpus visualization, but still there is no such a comprehensive survey on it. So, in this study, the research in document corpus visualization with 3D layout, or 3D document corpus visualization, is investigated and this investigation is mainly around 2 function units in the visualization pipeline (Card *et al*., 1999): spatial layout and interaction.

As shown in Fig. 1, the visualization pipeline can be segmented into 5 function units: preparation, data reconfiguration, spatial layout, display and interaction. While preparation is just to prepare the raw information stored as binary data or characters in the computer, data reconfiguration tries to transform them into target visualization dataset by analysis and filtering. Spatial layout focuses on how to map the reconfigured dataset to 1D, 2D or 3D space and show the layout to the user through view transformation. The last unit, interaction, allows the user to modify all the intermediate transformations dynamically and thus controls 3 function units: data configuration, spatial layout and display.

In this pipeline, the position of document corpus can be clearly found out. Based on the idea of Morse (1997), document can be defined as a file that has content with particular structure and metadata. The metadata can be author, publisher, subject and so on. Therefore, in Fig. 1, document corpus is not the raw data, but the transformed raw data, i.e., dataset and its final view is affected by spatial layout, display and interaction.

To techniques in these 3 function units affecting 3D document corpus visualization, display technique is on 2D view, it is spatially less flexible than 3D spatial layout technique and it is affected by both spatial layout and interaction techniques, therefore existing studies on document corpus visualization emphasize more on the techniques of spatial layout and interaction than display.

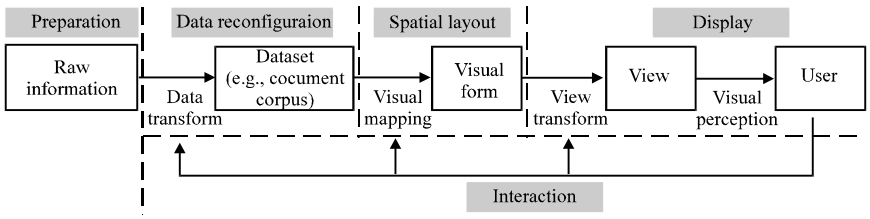

Fig. 1: Five function units in the visualization pipeline

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So, this study also focuses on these two units. For spatial layout, 4 styles of layout techniques (node-link, cluster, virtual widget and miscellaneous) and 2 types of layout augmentation methods are presented. For interaction, 4 styles of interaction (3D walkthrough, filter and specification, placement and annotation) and 2 types of interaction augmentation methods are also suggested. Application area is also interesting to who wants to find similar studies in the same area, therefore existing studies are discussed further with the 2 function units and 7 application areas (book, task oriented management, hierarchical management, mixed document management and mixed information management) and then some interesting findings and future directions are obtained.

Another interesting consideration in the layout dimension is called 2 1/2 dimensions (2 1/2 D) (Jacquemin *et al*., 2006; Marr and Nishihara, 1978; Ware, 2001). It is the intermediate step of visual perception from 2D to 3D which tries to add 2D sketches (layout) with 3D depth and orientation information. Since the objects are defined in 3D in study focusing on 2 1/2 D design, these papers are assumed to have 3D layout in this survey.

This survey confines to studies that are directly for 3D document corpus visualization or that have applied explicitly to it so that a general view of the research status quo in it can be got.

There are general discussions on visualization or information visualization, (Lorensen, 2004; Tory and Möller, 2002, 2004; Van Wijk, 2006) and reviews on information visualization (North, 2006).

However, survey on information visualization which document visualization belongs to is not easy because it is widely covered and new ideas continuously appear. Three papers trying to review it from a specific topic are very interesting. Two of them (Benford *et al*., 1999; Wiss and Carr, 1998) specially focus on 3D visualization and the left one (Morse, 1997) is perhaps the single article till now on document visualization. While Wiss and Carr (1998) summarizes the research in 3D information visualization with three cognitive aspects (attention, abstraction and affordances), Benford *et al*. (1999) investigates the World Wide Web visualization around a wide range of topics such as network structure, web pages and users. For the document visualization survey (Morse, 1997), different document visualization methods, interaction issues and different task models are discussed. But 3D layout is not discussed in detail because this survey is not specially for it. This paper is also hard to explain some new interaction method, such as annotation and the studies it referred are rather old.

Although, document is an important source of information and, during the past years, there are a lot of papers in 3D document collection visualization, there is no such survey till now. Therefore, this study presents such a survey based on the visualization pipeline. This report is mainly around 2 units: spatial layout and interaction. Four styles and 2 augmentation types for 3D spatial layout and 4 styles and 2 augmentation types for interaction are presented for investigation. Future discussions on interesting findings and future directions are with additional 7 application areas.

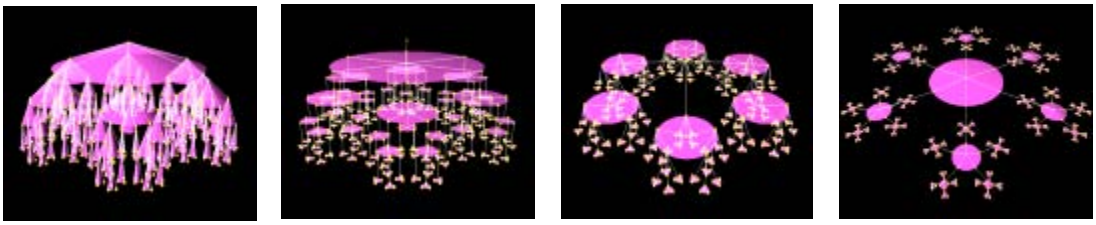
SPATIAL LAYOUT TECHNIQUES

Spatial layout utilizes the spatial memory of human being. There are 4 styles of 3D spatial layout techniques, including node-link, cluster, virtual widget and miscellaneous and 2 types of techniques for augmenting layout, including focus+context and photo-realistic rendering.

The spatial layout styles: For the 4 layout styles, node-link uses both node and link while cluster displays clusters of nodes without visible links. Virtual widget simulates the real document collections with virtual pages or document holders. All design methods do not belong to node-link, cluster or virtual widget are named to be miscellaneous.

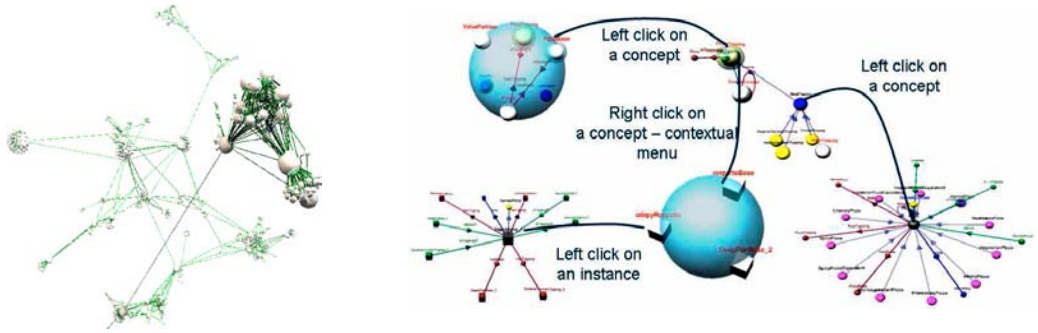
Node-link: The node-link layout can be tree or graph. Tree usually depicts the hierarchy of the document base while graph usually shows networked (relational) web pages or semantic metadata.

For tree, one of the early methods is Cone trees and Cam trees (Cockburn and McKenzie, 2000; Robertson *et al*., 1991) where, each sub-tree is a cone with apex as the node and all children are arranged around the cone base. Since parts of the cone tree may not be seen and there will be clutter for too many nodes, Cone tree can not display very large hierarchical structure. Carriere and Kazman (1995) tried but still could not remove the clutter when the tree is projected to the 2D surface. Reconfigurable Disc Trees (RDT) (Jeong and Pang, 1998) can remove all clusters for large hierarchy by dynamic adjustment of the tree structure and therefore solves the overlap problem of 2D projection. As Fig. 2 shows, RDT can have several shapes to enhance user perception. Similar to RDT is OCEAN (Jacquemin *et al*., 2006). In OCEAN, the child node distances are decided by the similarities of children and child nodes are inside the parent node disk while, in RDT, they are on its outer circumstance. Another interesting idea is botanical tree (Kleiberg *et al*., 2001), which is based on the simplified Holton model to visualize the non-leaf nodes as branches and sub-branc1hes with leaf nodes as fruits.



(a) Cone tree (b) Disk tree (c) Compact disk tree (d) Plane disk tree

Fig. 2: Display of various trees with 516 nodes (Jeong and Pang, 1998)



(a) Representation of complex web structure with narcissus (Hendley *et al*., 1995)

(b) The user interface of OntoSphere3D (Bosca *et al*., 2007)

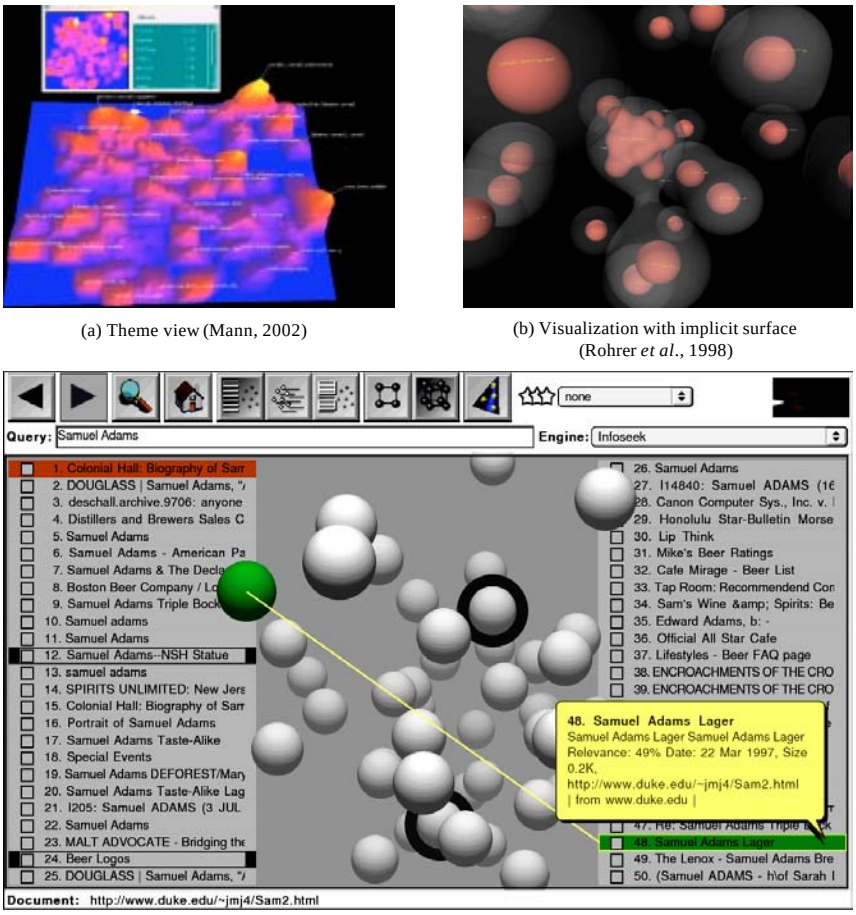
Fig. 3: Node-link examples in graph

Graph is especially suitable for web environment. The early system called Narcissus (Hendley *et al*., 1995) visualizes the relationship between documents or other information where repulsive and attractive forces (if there is a link) are used between web pages. Figure 3a shows several hundred web pages of different types are linked together. For semantic web (Berners-Lee *et al*., 2001; Wikipedia, 2008), some studies visualize the interconnected relationships of metadata. Telea *et al*. (2003), based on GViz (Telea *et al*., 2002) where, 3D staked layout can be used, proposed a method to visualize RDF structures. In this method, Graph nodes and RDF graph edges are represented by rectangles and fading lines respectively. 3DVis (Papamanthou *et al*., 2005) uses the third dimension to display the isa relationships and the plane to display the property links so that the semantic differences between these two links are emphasized. A more complex method is OntoSphere3D (Bosca *et al*., 2007), where, different node-link views for different scene elements are connected to visualize the internal relationships. Figure 3b shows its interface that different objects represent different scene elements. For the topic map visualization, Grand and Soto (2000) proposed a tree visualization method based on cone trees.

When there is no explicit link needed between nodes, the layout is not a node-link style any more but a cluster style.

Cluster: Perhaps the best known approach is ThemeScapes (Wise *et al*., 1995) also known as ThemeView which displays the clustering result as 3D landscapes. As Fig. 4a shows, ThemeView uses elevation to show theme strength and other features such as valleys and peaks to show interrelationships among documents and their themes. While theme spaces uses distance to place neighboring documents, Bead Chalmers and Chitson (1992) and Rohrer *et al*. (1998) utilize potential fields and mass-spring model, respectively. As Fig. 4b shows, Rohrer *et al*. (1998) also modeled document as implicit surface with each surface cluster as the blend result of closely related documents.

Cluster is also used to visualize the retrieval results. SENTINEL (Fox *et al*., 1999) utilizes a multi-level visualization to let the user selectively view different aspects of the document topics. Lighthouse (Leuski and Allan, 2000) uses the clustered spheres to show the similarities of documents retrieved, Fig. 4c shows the



(a) Theme view (Mann, 2002)

(b) Visualization with implicit surface (Rohrer *et al*., 1998)

(c) Lighthouse visualization of searching Samuel Adams (Fox *et al*., 1999)

Fig. 4: Cluster examples

visualization for the top fifty query results of 'Samuel Adams' with Lighthouse. A more complex system called WebSearchViz (Nguyen-WEB; Nguyen and Zhang, 2006) where, the query and the documents are the sun and the planets, respectively. Movement, speed and distance are used to visualize the relevance among a query and the search results.

While studies mentioned above rely on abstract geometrical shapes, e.g., node and surface, to describe document corpus, some other papers use another quite different style called virtual widget.

Virtual widget: Virtual widget can be a virtual book or other virtual objects to simulate the real document management.

The natural idea is virtual book. While the earlier WebBook (Card *et al*., 1996) allows the user to make 3D books out of related web pages as a 3D browser, 3Book (Card *et al*., 2004) supports more advanced features, such as visualizing large book and interaction. Another similar work was introduced by Chu *et al*. (2003, 2004) for realistic book where a complex integrated model (including the front, back, middle page and left and right pages) is used for a more natural look than 3Book. Figure 5a shows turning a single page in this system.

Except book, room like virtual widget is also studied for document management. The early research, perspective wall (Mackinlay *et al*., 1991), tries to fold a 2D layout into 3D perspective wall to display text with focus +context effect (Focus+context effect will be discussed later). To utilize the empty space around perspective wall, Win3D (Mitchell and Kennedy, 1997) uses the space including the floor, ceiling and walls. Similar but more complex work is task gallery (Robertson *et al*., 2000; Research, 2005), which builds a virtual gallery consisting of many rooms for task management. Figure 5b shows one room of task gallery which can be thought as a gallery with paintings representing tasks.

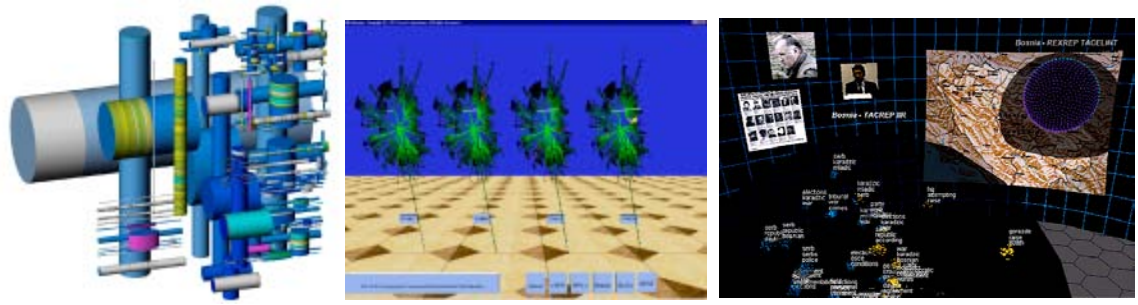
Virtual desk is also used for holding virtual books or documents. The earliest perhaps is WebForager

(a) Turning a single page ofa realistic book (Chu *et al*., 2004)

(b) Task gallery (Research, 2005)

(c) WebForager (Card *et al*., 1996)

Fig. 5: Virtual widget examples



(a) A ?le system rendered with beamtree (Van Ham and Van Wijk, 2002)

(b) Time tube (Chi *et al*., 1998)

(c) An security application of starlight (PNNL Laboratory, 2008)

Fig. 6: Miscellaneous examples

(Card *et al*., 1996), as showed in Fig. 5c, which collects the web pages and the WebBooks hierarchically with a focus place, an immediate memory space and a tertiary place. Another highly referenced work, data mountain (Czerwinski *et al*., 1999; Robertson *et al*., 1998), uses a virtual desktop. Similar to data mountain but with comparatively simpler interaction is Lookmark (Breiteneder *et al*., 2002) which bookmarks the web pages. Similar to the start palette in task gallery, Wang *et al*. (2005) used a 3D carousel view to display the documents, but with more efficient design considerations, such as animation, varying spatial layout and the termination marker.

Node-link, cluster and virtual widget are the 3 main layout styles, but there are some other interesting styles that are hard to generalize and thus all those are called miscellaneous.

Miscellaneous: For hierarchical structure visualization, information cube (Rekimoto and Green, 1993) and collapsible cylindrical trees (Dachselt and Ebert, 2001) use embedded cubes and rotation cylinders, respectively. Figure 6a shows beam trees (Van Ham and Van Wijk, 2002) based on the spatial order of rectangular nodes Carter and Capretz (2003). 3D User visualized a 3D file management system based on Half Life engine and realized functions such as copy and cut. Bray (1996) visualized the website collections by displaying different websites in different looks under different properties. VRWeb 3D viewer of (Andrews, 1995) has similar idea.

While all earlier studies mainly focus on static features of document collections, dynamic features are also studied. Chi *et al*. (1998) proposed a WEEV (Web Ecology and Evolution Visualization) system to show the evolution of a web site with disk tree. As showed in Fig. 6b, when disk trees are organized according to time evolution, a time tube can be got. Chiu and Truong (2002) proposed space-time browser which integrates space (x and y axes) and time (z-axis) to visualize and retrieve documents.

Gilson *et al*. (2006) used user defined elements to visualize ontologies of semantic web. Cubaud *et al*. (2005) interactively visualized a movable book by modeling it with a scene graph of camera captured movable parts and the main page.

There are also two systems accumulating different techniques together: Information visualizer (Robertson *et al*., 1993) and starlight (Risch *et al*., 1997).

In comparison between them, the former focuses on scheduling tasks to realize fast information access and interaction without discussion on displaying different types of information at the same time while the latter tries to analyze and simultaneously visualize several types of information together. Figure 6c shows an example of Starlight where four different types of information (human intelligence reports, tactical intelligence reports, reports on movements of military vehicles and reports on radar activity) are visualized together.

Additional comparison remarks: After above discussions of the 4 styles for 3D spatial layout, additional comparison remarks are got:

Node-link is good at structure while cluster is good at aggregated results around themes or metrics. Virtual widget, on the other hand, tries to simulate the real environment. Node-link and cluster emphasize more on interrelations than the document itself, but virtual widget emphasizes both of them. For miscellaneous, different research has different highlight depending on what its focus is.

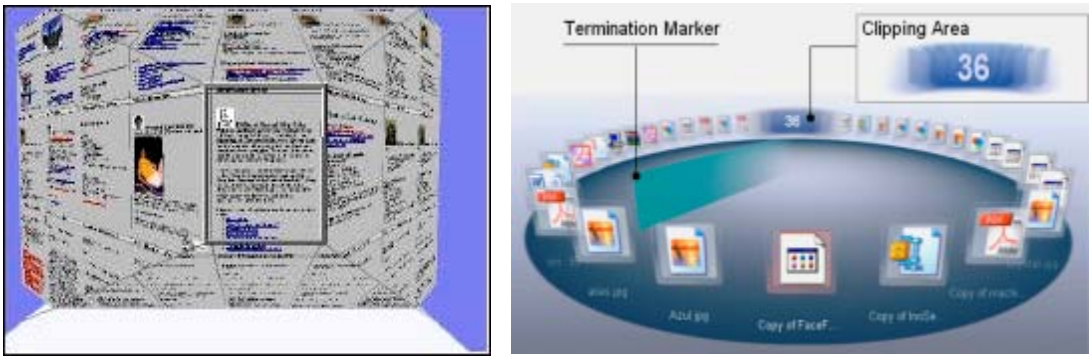
Since, the geometrical objects in node-link and cluster are rather simple, the difficulty of those 2 styles is in the interrelation between objects. However, since the interrelation of virtual widgets can be visually precept by the user, how to design a vivid widget is challenging. For miscellaneous, the difficulty is different between different methods.

Except above styles of spatial layout, there are two types of techniques trying to augment spatial layout.

Layout augmentation: Layout augmentation enhances layout by additional transformation or rendering. Two types of methods are used among existing studies, focus+context and photo realistic rendering. The former visualizes the specific object in larger size while displaying all other objects in smaller size so that global context can be captured and the latter adds the virtual scene the natural looks (such as shadow and shading) of real world.

For focus+context, it is omitted by many papers since the object will be automatically zoomed in when the object is in the focus for a perspective view. But, the display model can also be manually adjusted to have an exaggerated effect. In Perspective Wall, a central panel is used for details and two side panels are for context. Win3D steps further to use surrounding panels for context display. Task gallery has the similar design. In WebBook, as Fig. 7a shows, a document lens (Robertson and Mackinlay, 1993) is used to view an interested page while still showing all other pages in a comparatively smaller size. In the study, on implicit surface model (Rohrer *et al*., 1998) (Fig. 4b), the shape of single document is displayed along with the global shape of the cluster as a shell surrounding the document. Another method is proposed in 3D carousel view where extra bins are visualized as a clip area and thus give the user the impression of a lot of bins inside. Figure 7b shows the clip area existing in the 3D Carousel interface, in which number 36 means 36 bins inside it.

For photo realistic rendering, the popular methods are shading, shadow and transparency. The papers that use shading are (Jeong and Pang, 1998; Mackinlay *et al*., 1991) (Fig. 2) and the papers that use shadow are (Jacquemin *et al*., 2006; Robertson *et al*., 1998, 1991, 2000; Van Ham and Van Wijk, 2002) (Fig. 5b, 6a). In Chu *et al*. (2004) (Fig. 5a), transparency is used to simulate the transparent page. In lighthouse (Fig. 4c), fog is used to create the depth feeling, i.e., the farther of the object and the closer to the background color. Shading, shadow and transparency are also used for other purposes rather than photo realistic rendering. For example, in (Hendley *et al*., 1995; Rohrer *et al*., 1998) (Fig. 3a, 4b), transparency is



(a) Document lens in WebBook (Card *et al*., 1996)

(b) Clip area in 3D carousel (Wang *et al*., 2005)

Fig. 7: Focus+context examples

used to show the conglomerated cluster and the Information Cube also uses semi-transparency to show the embedded cubes. In beamtrees (Fig. 6a), shading also indicates the direction of subdivision. OntoSphere3D (Fig. 3b) uses transparency and opaque to show different semantic relations, i.e., the former represents direct relation and the latter represents inherited relation.

Till now, the spatial layout techniques have been reviewed. With them, a static 3D scene can be got and final 2D view can be got with display as the pipeline in Fig. 1 shows. To fully explore the 3D space for a vivid view, dynamical update called interaction is very important and it will be reviewed in the next section

INTERACTION METHODS

There are 4 styles of interaction methods, including 3D walkthrough, filter and specification, placement, annotation and 2 types of interaction augmentation techniques, including multimedia and animation.

Interaction styles: For the 4 interaction styles, 3D walkthrough lets the user be close enough to clearly see the objects, filter and specification filters out the uninteresting objects and specifies the looks of displayed objects, placement allows the user move an object from one place to another place or replace it with another object and annotation realizes some interactive operations on a virtual document like those on a real book.

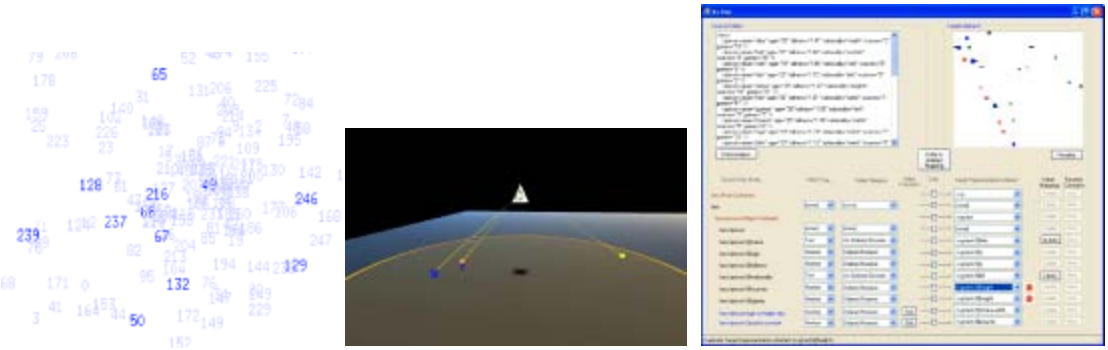
3D walkthrough: 3D walkthrough means virtual walking in 3D space, including going up or down, left or right and front or back. It also includes rotating or selecting an object. Selection normally relates translation and rotation because the whole scene will rotate and translate itself to let the selected object be in front of the viewer. 3D walkthrough can be restricted depending on the specific model used (Breiteneder *et al*., 2002; Dachselt and Ebert, 2001; Jacquemin *et al*., 2006; Robertson *et al*., 1998). For example, in data mountain, the walkthrough is only allowed on the surface of the desktop but not below the desktop.

3D walkthrough is very common since it is easy and necessary to implement with 3D spatial layout and thus our main attention is the other 5 methods. First is filter and specification which is widely used by many studies as our next discussion shows.

Filter and specification: Filter in many studies is implemented as a query or search and the objects will normally change their appearance to reflect the search results. Color is widely used in studies, such as lighthouse (Fig. 4c), lookmark, bead and SENTINEL. Figure 8a shows an example of Bead where different intensities of blue article IDs mean the different distances of the articles to the query. Other visual properties of objects are also used to reflect the query. Rohrer *et al*. (1998) (Fig. 4b) uses not only color but also shape and textures. In 3D carousel, the highlight vector can be changed so that the selected bins will change consequently.

Filter is also implemented as complete removal of the unselected objects. WebSearchViz allows user to filter out low similarity documents by creating a filter circle. The 3D file manager in (Carter and Capretz, 2003) provides basic file operations, such as cut and deletion. In OCEAN, as showed in Fig. 8b, all other nodes are masked out to show only the selected node and its child nodes.

Filter result is sometimes presented as a quite different view. In ThemeScapes, a slice of 3D view can be also visualized to obtain different aspects of view. In reconfigurable disc trees (Fig. 2), configuration operation is provided to dynamically change the shape of the tree.



(a) Search result in bead (Chalmers and Chitson, 1992)

(b) Masking result in OCEAN (Jacquemin *et al*., 2006)

(c) VizThis interface (Gilson *et al*., 2006)

Fig. 8: Filter and specification examples

Some studies discuss complex filter operations. Narcissus provides more detailed filter operations such as selectively showing objects and their properties. In cone trees, hiding selected parts called gardening operations is provided and search is also supported by visualizing differently relevant tree nodes and trucks in different colors and sizes. Starlight has two query classes, content queries and association queries, to interactively visualize the elements and their relationship.

For specification, apart from specifying the search result as discussed above, it can also be used to distinguish different objects. For example, in VRWeb 3D Viewer, the user can specify the model of an object and in ocean, the user can choose to show the direction tags in the scene. Specification can also be utilized by semantic web visualization. For example, in the research of topic map visualization of (Grand and Soto, 2000), the selection of a particular topic and association is also supported and the specified elements can be displayed in a separated 3D window. In VizThis, showed in Fig. 8c the user can select different mapping models to represent different entities. Similar idea to VizThis can also be found in OntoSphere3D. More complicate operations can be found in GViz where three main operations (selection, graph editing and mapping) are used to personalize the 3D output.

For above 2 interaction methods, the scene graph can not be changed by the user immersing into the scene directly, but the following 2 interaction methods, placement and annotation, supports direct operation on objects. Placement allows the user to move the object from one place to another and annotation allows the user to annotate the virtual object.

Placement: As showed in Win3D, Data Mountain, Task Gallery and Lookmark, placement can be clicking a page to display it as the focusing page, clicking it back to its original position or clicking a link to open another page. It can also be moving the page from one place to another place as in data mountain and lookmark. Figure 9a shows clicking action on the foremost page in Data Mountain that brings the page to be in front of the user.

Placement can be interpreted as turning pages. In WebBook, the user can drop a page on a book, turn pages, click bookmarks and hyperlinks in the book to reach other pages. But there is no deformation during this action and thus let the action look unreal. As the example showed in Fig. 9b, two researchers (Card *et al*., 2004; Hong *et al*., 2006) discuss how to turn the pages of 3Book with imaginary cone modeled page to realize deformation. Chu *et al*. (2003, 2004) (Fig. 5a) used a mass-spring model to depict this process.

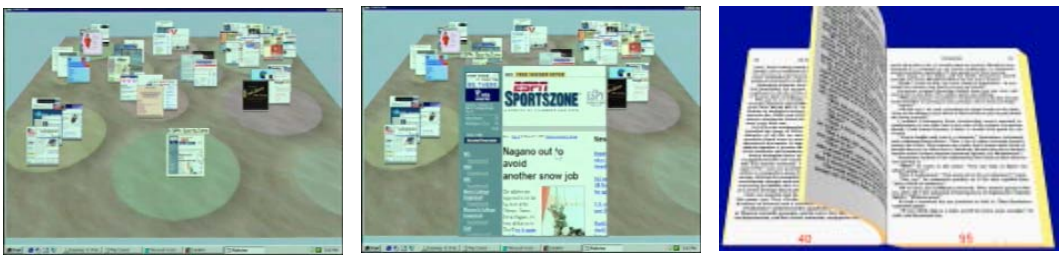
For non turning page placement, to the movable book of Cubaud *et al*. (2005), movement of the model in the virtual page is also supported. SpaceTime browser allows user to place the document to different region so that possible change on the time such as schedule change can be reflected.

Except placement, annotation also tries to imitate the real action during reading.

Annotation: Annotation can be scribbling notes, drawing figures and so on. Hong *et al*. (2005) discussed the annotation technique for 3Book based on geometrical modeling and rendering techniques and they claimed that their work is the first work of annotation on 3D documents. Figure 10 shows two frames generated with the hybrid technique based on texture and 3D transparent geometry to scribble PARC TAP in the top margin.

Additional comparison remarks: After introduction the 4 interaction styles, additional comparison remarks can be obtained.

3D walkthrough is more natural and the easiest among them. Placement and annotation are most difficult among them because a suitable model is required along with real time deformation and interaction. Filter and specification need modify some existing properties of the

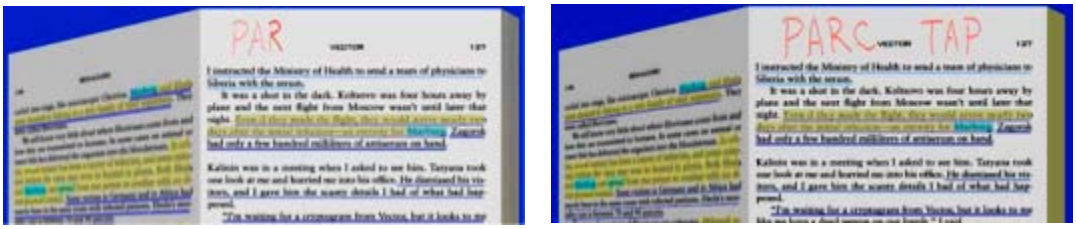


Before clicking the front page | After clicking the front page

(a) Example placement of data mountain (Research, 2002)

(b) Turning a page block of 3Book (Card *et al*., 2004)

Fig. 9: Placement examples



(a) One intermediate frame (b) The final result

Fig. 10: Scribbling in a virtual book (Hong *et al*., 2005)

scene graph and thus it is the second in difficulty. But the defect of 3D walkthrough is it will let the user be lost during walkthrough if it is not properly designed.

Placement and annotation are especially suitable for virtual widget style of layout because they all try to imitate the real action with real document. To other 2 interaction methods, they are applied to all types of layout.

Beyond the 4 interaction styles, there are 2 types of augmentation technique in interaction.

Interaction augmentation: Interaction augmentation tries to enhance interaction by additional rendering techniques. Generally, 2 types of methods are used to enhance the interaction: multimedia and animation.

Multimedia normally means not only text but also images and sounds are used so that more information can be provided to the user. In Task Gallery and Data Mountain, sound is used to mimic the moving of documents. In Starlight as showed in Fig. 6c, image and map are used to concurrently display related information.

Animation aims to realize smooth transition. It can be used to show the perspective rotation around the center of the mass (Chalmers and Chitson, 1992) and the process of the selected objects appearing to be the focus, such as (Bosca *et al*., 2007; Mackinlay *et al*., 1991; Robertson *et al*., 2000). In Jeong and Pang (1998), animation is used to show the deformation process of one object to another object. In Data mountain, page avoidance is realized by animating the pages to move aside and back. For book like applications (Card *et al*., 1996, 2004; Chu *et al*., 2003) (Fig. 5a, c and 9c), turning page is also the main object of animation. Especially, for 3Book, multi-resolution strategy is used to realize real time texturing during turning page and for (Chu *et al*., 2003), page turning process is pre-computed and stored for real-time play during page turning. Except those animations for static objects, animation can also imitate the motion of rotation objects. 3D Carousel uses acceleration and breaking forces together to imitate the rotation of real carousel. WebSearchViz uses the rotation speed of the document to depict the similarity of subjects.

Till now we have finished review the related study based on the 2 function units in the visualization pipeline: spatial layout and interaction.

FURTHER DISCUSSIONS WITH APPLICATION AREA

Application areas: According to different application purposes, application areas can be roughly divided into semantic web, the world wide web and non web. For non web, more detailed classification can be got, including book, task oriented management, hierarchical management, mixed document management and mixed information management. Book visualizes a real book. Task oriented management clusters documents with different purposes (tasks). Hierarchical management, on the other hand, hierarchically organizes documents. Mixed document management manages documents in partially hierarchical and partially clustered way while mixed information management copes with information from not only documents but also other types of information. Here, application area is used to further discuss related studies to get some interesting findings and define some future directions.

DISCUSSION

Table 1 shows the result of the summary according to spatial layout, interaction and application area of present study. Both layout augmentation and interaction augmentation are given in italics in the same column of spatial layout and interaction respectively. Since almost all studies can support 3D walkthrough no matter whether it is specified clearly in the research or not, it is not shown in the Table 1. Figure 11a and b shows the comparison of application area with spatial layout and interaction respectively. With Fig. 11, the following findings can be obtained.

Table 1: Summary of existing studies with application area, spatial layout and interaction

Application area	Interaction	Spatial layout	Studies
Semantic web		Node-link	3DVis (Papamanthou *et al*., 2005)
	Filter and specification	Node-link	Sphere3D (Bosca *et al*., 2007)
	Animation	Photo-realistic rendering	
	Filter and specification	Node-link	Topic map visualization (Grand and Soto, 2000)
	Filter and specification	Node-link	GViz (Telea *et al*., 2003; Telea *et al*., 2002)
	Filter and specification	Miscellaneous	VizThis (Gilson *et al*., 2006)
World Wide Web	Filter and specification	Cluster	WebSearchViz (Nguyen and Zhang, 2006; Nguyen-WEB)
	Animation		
	Filter and specification	Cluster	Lighthouse (Leuski and Allan, 2000)
		Photo-realistic rendering	
	Filter and specification	Virtual widget	Lookmark (Breiteneder *et al*., 2002)
	Placement		
	Placement	Virtual widget	WebBook and WebForager (Card *et al*., 1996)
	Animation	Focus+context	
	Placement	Virtual widget	Data Mountain (Robertson *et al*., 1998)
	Animation	Photo-realistic rendering	
	Multimedia		
		Miscellaneous	Visualizing the Web (Bray, 1996)
	Filter and specification	Miscellaneous	VRweb and Information Landscape (Andrews, 1995)
	Animation	Miscellaneous	Disk Tree and Time Tube (Chi *et al*., 1998)
Book	Annotation	Virtual widget	3book (Card *et al*., 2004; Hong *et al*., 2005; Hong *et al*., 2006)
	Placement		
	Animation		
	Placement	Virtual widget	Realistic books (Chu *et al*., 2003; Chu *et al*., 2004)
	Animation	Photo-realistic rendering	
	Placement	Virtual widget	Movable book (Cubaud *et al*., 2005)
Task oriented management	Filter and specification	Virtual widget	3D Carousel (Wang *et al*., 2005)
	Animation	Focus+context	
	Placement	Virtual widget	Task gallery (Robertson *et al*., 2000)
	Animation	Photo-realistic rendering	
	Multimedia		
Hierarchical management		Node-link	Cone tree (Robertson *et al*., 1991)
	Animation	Focus+context	
		Photo-realistic rendering	
	Filter and specification	Node-link	Reconfigurable disc tree (Jeong and Pang, 1998)
	Animation	Photo-realistic rendering	
	Filter and specification	Node-link	OCEAN (Jacquemin *et al*., 2006)
	Animation	Photo-realistic rendering	
		Node-link	Botanical tree (Kleiberg *et al*., 2001)
		Miscellaneous	Information cube (Rekimoto and Green, 1993)
	Animation	Photo-realistic rendering	
	Filter and specification	Miscellaneous	3D File Manager (Carter and Capretz, 2003)
		Miscellaneous	Beamtress (Van Ham and Van Wijk, 2002)
		Photo-realistic rendering	
		Miscellaneous	Collapsible Cylindrical Trees (Dachselt and Ebert, 2001)
Mixed document management	Filter and specification	Node-link	Narcissus (Hendley *et al*., 1995)
		Photo-realistic rendering	
		Cluster	IVORY (Gross *et al*., 1997)
	Filter and specification	Cluster	Sentinel (Fox *et al*., 1999)
	Filter and specification	Cluster	ThemeScapes (Wise *et al*., 1995)
	Filter and specification	Cluster	Bead (Chalmers and Chitson, 1992)
	Animation		
	Filter and specification	Cluster	Implicit surface (Rohrer *et al*., 1998)
		Focus+context	
		Photo-realistic rendering	
	Animation	Virtual widget	Win3D (Mitchell and Kennedy, 1997)
		Virtual widget	Perspective wall (Mackinlay *et al*., 1991)
	Animation	Focus+context	
		Photo-realistic rendering	
	Filter and specification	Miscellaneous	SpaceTime browser (Chiu and Truong, 2002)
	Placement		
Mixed information management	Filter and specification	Miscellaneous	Starlight (Risch *et al*., 1997)
	Multimedia		
	Filter and specification	Miscellaneous	Information visualizer (Robertson *et al*., 1993)
	Placement		
	Animation	Focus+context	
	Multimedia	Photo-realistic rendering	

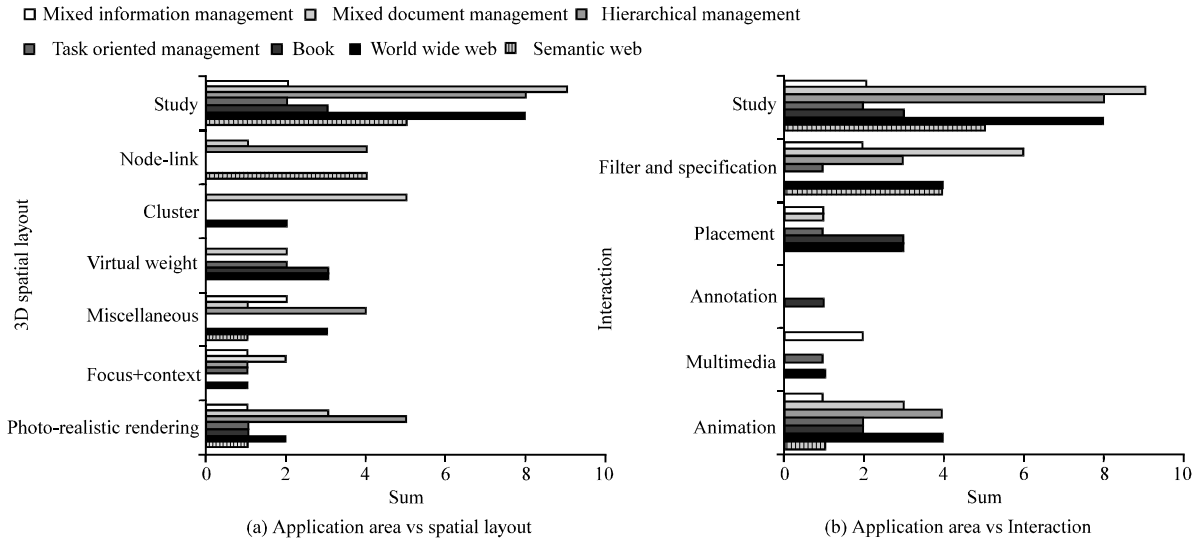


Fig. 11: Statistical comparison

- Mixed document management, hierarchical management and world wide web receive more attention (25 studies in all) that other application areas. It means those types of application area are more common than others. Studies on other application areas need to discover in the future
- Node-link is preferred by semantic web (4 studies) and cluster is only used by World Wide Web and mixed document management (7 studies in all). This one is beyond our expectation at least hierarchical management should also prefer node-link and world wide web also can be visualized as node-link
- Placement is a very interesting research topic (10 studies) although it is not easy to realistically realize. Considering the difficulty of placement, it is more attractive because it tries to simulate the real actions
- There is only one study in annotation and thus more researches on it are required since it is quite new
- Focus+context and multimedia (10 studies in all) are less popular than other 2 types of augmentation (31 studies in all). While focus + context can be replaced by the perspective view, multimedia can be studied more in the future because it augments the visualization.

With these findings, some interesting directions for future research can be obtained:

- **Collaborative document visualization:** This direction focuses on how to collaborate people from different places to realize document visualization so that any modification from one site can be visualized immediately by people from other sites. There has been similar work in other information visualization area, such as Grimstead *et al.* (2005), but there is no such study in 3D document corpus visualization
- **Semantic web with multimedia:** Recently semantic web has been the hot topic for document visualization. Although a lot of work tries to visualize ontologies or metadata, there is almost no work to visualize multimedia content of semantic web, especially now MPEG-7 (Manjunath *et al.*, 2002; Salembier, 2002) adopting XML as its DDL
- **Annotation with multimedia:** Annotation occupies a large part of our reading but there is only one paper focusing on it till now. Future consideration on it can be annotation with more multimedia content, for example, the user can add an image or audio to the interested text
- **Stylesheet and personalization:** Stylesheet is very useful in personalize the output. Recently there has been some work (Bizer *et al.*, 2006; Pietriga, 2006) on how to get 2D personalization with stylesheet but how to realize 3D personalization
- **Personal document management:** Accompanying with wide spread of electronic documents, the documents of an ordinary person are increasing very fast. A visually attractive, convenient and powerful management tool for such large quantities of documents is very interesting. With such tool, any interested articles can be kept for later reuse and the user can easily find the document with simple interaction in 3D virtual interface

- **New interaction:** This direction is more general on how to get an new interaction method, not just the interfaces of almost all existing studies that are built on 3D geometrical objects linked or not and interfered by limited mouse and keyboard input. As described by Beaudouin-Lafon (2004), a shift from designing interaction rather than simply designing interfaces is needed although it is hard to put forward a new interface

CONCLUSION

This study surveys 3D document corpus visualization research mainly around the 2 function units of the visualization pipeline, spatial layout and interaction. We presented 4 styles of spatial layout (node-link, cluster, virtual widget and miscellaneous) with 2 types of augmentation techniques (focus+context, photo-realistic rendering) for the former and 4 styles of interaction (3D walkthrough, filter and specification, placement, annotation) and 2 types of augmentation techniques (multimedia and animation) for the latter. In addition, for those who are interested in studies of the same application domain, application area is also used to further discuss the research and some interesting findings and future directions are introduced. Since document collections are an important source of information and this survey has never appeared before, it offers a significant milestone for future study in the area of document collection visualization.

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