Comparing Visualization Techniques to Structure Collaborative Concepts

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***Abstract*—Much research has been devoted to collaborative tools for writing, group communication, reviewing, managing projects, and developing network infrastructures to support sharing activities. However the creation and display of foundational collaborative concepts that manage group work has not been paid significant attention. Information visualization potentially addresses the progression of distributed concept building and presentation by visually representing group-generated concepts. This paper analyzes current visualization-based techniques including tag clouds, node-link diagrams, and mapping structures in a web-based environment. The analysis contributes to exploring the use of visualization tools for creating group concept structures that organize ideas for documents, projects, or specifications in academia and industry. A comparative features table is built and used as a basis for presenting an initial interface design to develop a collaborative visualization tool for concept management. Implications for future work include visualization system interface design, user evaluation, and adaptation to mobile collaborative visualization environments.**

Index Terms*—visualization, collaborative work, user interfaces, design

I. Introduction

Collaboration has morphed into the social web where supporting tools that are equipped with social features facilitate participatory work among two or more individuals in academia and industry. The transformation of a peer to peer or one-to-one communication process to a one-to-many dynamic endeavor is driven by well known applications such as Google Docs & Spreadsheets, Flickr, wikis, and also by the increasing practice of collective creation which is enhanced by the social web. Alongside this momentum is the vigorous development of information visualization tools that were originally conceived for single users, but now can offer sharing activities for multiple users. The standard definition of information visualization is the computer's visual rendering of abstract information to allow cognitive amplification and insight into a collected data set [3]. Cognitive amplification in this paper's context results from the visualization of abstract ideas generated by end-users in order to create a fluid picture and visual workspace where collaborators may organize, add, delete, and substantiate ideas to manage, build, and make decisions about collaborative work.

The synthesis of visualization and collaboration using structural visualization representations, such as concept or mind maps, yield a promising method to allow insight and make visible the abstract conceptual structure that is the primary guide to the volatile components of the collaborative process. The components for concept organization include sharing, linking, building, and augmenting constructs that underlie and result in group-based work. Information visualization relies heavily upon the large bandwidth of human visual processing and collaboration relies upon the creation and merging of abstract ideas. By capitalizing upon humans' visual processing mechanisms, visualization makes abstract entities (ideas/concepts) into more tangible entities that provide pillars for project development. Visualization approaches not only aid the building and organizing process, but also take advantage of multiple users' sense of sight for pattern recognition and preattentive processing that can be used effectively for perceiving a conceptual picture of shared work. Preattentive processing refers to the human ability to perceive entities before cognition is applied [19].

Several issues emerge in combining visualization with collaborative planning and the task of visually structuring collaborative conceptual structures for group work requires further attention. This paper addresses this problem in two ways: first, an analysis of web-based tools for creating visual structures is conducted, and second, an initial interface design is developed on the basis of previous designs. The overall question which guides the initial analysis is: Which features exist in current web-based visualization tools that are conducive to managing collaborative conceptual structures?" The systems are explored and the findings are then used to generate an initial design idea for structuring collaborative concepts in a visual way.

Collaboration applies to two or more people working together. In this context, "concepts" refer to the ideas generated by one or more members of a defined distributed group of people who are cooperating on a given topic. "Conceptual structures" denote the arrangement and connection among the concepts presented for collaborator purposes. This paper introduces foundational research of collaborative structures and visualization in section two. Section three reviews three web-based applications for creating

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collaborative visual structures including tag clouds, node-link diagrams, and mapping tools. These models are selected as an exploratory point of departure since they share conceptual highlighting and relationship building factors for abstract information, such as ideas. The applications focus on organizing, building, and sharing features in a distributed environment. The paper concludes in section four by presenting an initial collaborative visualization design based on the features table generated from the visualization tool analysis. The analysis and resulting visual design address the issue of structuring collaborative concepts, serve as a foundation in the development of visualization tools, and provide a framework for developing collaborative mobile environments. Future work is then discussed.

II. RELATED WORK

A. Collaborative Tasks

Research is generally conducted on collaborative information seeking, which is the task of source consultation for idea generation. This line of investigation typically examines a different angle of the process for searching and sharing activities, but not necessarily the structuring of ideas from the search results. Morris [13] found that collaborative activities are well supported by web users for cooperative web search tasks and sharing search results. The refining of query terms or keywords by participants in the study was most closely related to distilling ideas into a keyword summary although the outcome is different. The former is used for generating a query and executing a web search, while the latter contributes to the formalization of a structure that is used for progressive idea development.

The information seeking process was also examined by Golovchinsky, Pickens, and Back [5] who developed a taxonomic structure based on collaborative dimensions such as concurrency and mediation depth. Most relevant to structuring activities is the location dimension. The authors noted that distributed collaboration requires the searchers' activities to be coordinated. This factor is described as using additional channels such as different types of conferencing. An additional visual channel may be added to these factors to not only manage the users' activities, but also to aggregate the resulting concepts into a visual arrangement for further examination, search, or written embellishment [5].

Visualizing ideas for group creativity emerged in a qualitative research study that found four breakdowns in the collaborative creative process [4]. The study used the BRIDGE (Basic Resources for Integrated Group Environments) tool and the collaborative workspace contained a concept map "to visualize ideas". However, the specific function of this feature is not immediately evident in their findings. The investigators' coding scheme defines several thematic elements that may be addressed by a viable visualization tool. These include: planning, showing multiple perspectives in order to make decisions, and implementing the selected perspectives. Two of the cited collaborative breakdowns include the insignificant attention paid to minor ideas and that new ideas were not maintained through the process. One future design consideration is to have the group's work displayed to them and to include the group's "activity awareness". The notion of idea summaries generated from log data is also considered as means of addressing creativity problems. These observations substantiate the possibility of adapting a structural visualization tool to represent multiple perspectives, idea sustenance, and activity awareness.

The movement toward using collaborative visual components is featured in a system analysis on the VERN online collaborative tool [21] that is designed to locate suitable meeting times for group collaboration. The system uses a straightforward graphical drag and drop interface to schedule meeting times for collaborators. In another study, the Factic system, uses personalized graphical navigation for search results. This is a collaborative feature that draws upon personalization and annotation of search results for particular user groups [18]. A hierarchical clustering visualization is used to present the search results. The clusters contain different data types, color denotes relevance, icon size represents the number of search results, and the distance between the clusters indicates topic similarity. The system is noted for supporting collaborative search and is described as inciting annotations and presenting search result attributes through the visualization. However, its purpose deviates from the overall collaborative concept synthesis that is addressed in this paper.

B. Visualization and Collaborative Structures

Current visualization studies focus well on collaborative problem-solving tasks especially in particular domains [1,20]. The task of building collegial conceptual structures requires users to consider the collaborative topic under discussion, consult sources, distill ideas, represent them as brief textual or keyword summaries, and arrange them within a shared framework. In addition, these tasks need to be incorporated into a visualization presentation. The visualization reference model features a standard tabular collection of data which undergoes a visual transformation to assist single users in obtaining insight into a large data set [3]. Collaborative data typically comprises a smaller data set that is subject to dynamic changes that invoke corresponding visualization changes in the display to facilitate progressive concept management. Multiple users not only gain insight on the conceptual process, but also create it.

The use of visualization for high-level understanding encompasses work in data graphics. For example, visual charts are used to display process flows or organizational charts of company personnel. Each icon in the chart represents a specific entity, such as people or processes that assist the end user in making decisions or updating the status of information in the display. Entities typically utilize size, color, and position to depict information to the users. Scatter plots, horizontal bar charts, line charts, and so forth are used for these purposes depending on the data type. Visualization's complexity is evident when it draws upon algorithmic techniques that present users with options to dynamically manipulate the display through interactive behavior. Data glyphs may be used to represent multidimensional data and while human perceptual processes are engaged for the visualization display, cognitive efforts may be enriched by the interaction elements that help end users to understand what they see.

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Details regarding co-located collaborative visualization tools and behavior are addressed by [8]. Particularly relevant are the factors needed to create collaborative environments in areas such as communication, workspace organization, and changing collaborative styles from individual to participatory contributions. Communication is expressed as the ability for individuals to be aware of each other's actions as discussed in [13] or that the display has changed. The notion of collaborative workspaces suggests that individuals should be allowed social interaction around the visual displays. Information visualization "view" is emphasized since it is a primary component of individual and participatory views. A view is dependent upon orientation and can include attributes of angle, rotation, and scalability. Web-based collaborative visualization tools are presented along with behavioral factors. While high-level visual structuring is not pointedly discussed, more research on "the structure and integration of collaborative contributions" is recommended [8]. This perspective is the current paper's primary objective.

Social interaction is combined with visualization to address collaboration in scientific environments [12]. Extending the collaborative space to include behavioral and social aspects of group activities in a visual way is a method that they define as improving the collaborative space. Further, the users' collaboratory utilizes social interaction and communication as means of enhancing the collaborative process using visualization techniques that contribute to a project's success. The authors review three of their web-based interfaces for collaboration and emphasize collective annotations as a pertinent criterion for collaborative work. Most striking is the image graph, which allows scientists to visualize a particular process and the relationships among the data components. The image graph uses a connected set of thumbnail images to depict a process. Process visualization is significant to the collective idea flow and offers theoretical similarity to visualizing the collaborative process itself.

The evaluation of a collaborative mind-mapping tool called GroupMind presents an initial glimpse of how visual mapping tools contribute to creative teamwork [14]. A semi-controlled experiment was conducted to evaluate the system for its impact on group work, problem solving, and collaboration for brainstorming activities. 80 participants were investigated for collaborative tasks on particular topics. Idea generation metrics were taken and some of the findings showed that participants in interaction groups generated more ideas for tasks while using GroupMind than a traditional whiteboard. Idea management in general was found to be better facilitated using the mind mapping tool. Coordinating concepts was reported to be challenging with GroupMind. Color was used for each participant which allowed the original author to be identified and indicated real-time participation. One subject could not distinguish the colors used for group member representation. Based on their findings, one of the authors' recommendations included the incorporation of formal mind-mapping in future system designs. The features of a group mapping tool are to be explored in the web context and in the preliminary design interface presented later in the paper.

III. VISUALIZATION TOOL ANALYSIS

Collaboration tools for activities such as writing, rating work, sharing documents, creating private social networks, building teams, sharing presentations, whiteboarding, and conferencing have emerged as part of the web's social development. This analysis of visualization tools in the distributed concept management area focuses on web applications that demonstrate visualization attributes, social interaction (e.g. sharing, commenting), and tools that are available to end users for creating concept visualizations. Each example will be analyzed and a comparative table of features will be developed to initially investigate visualization's contribution for organizing group concepts and to provide a foundation upon which an initial visualization design is established. The tag cloud, node-link diagram, and mapping visual structures are examined next.

A. Tag Clouds

Tag clouds can be horizontal, vertical, or radial information visualization representations of keywords or terms that are generated from sources such as social tagging, user annotations, and documents. Tag clouds are frequently used on social information sites and may be used for search query representation and categorical labels [7]. They appear on web pages and have been strongly associated with Web 2.0 development. Tag cloud terms are encoded by size and color to indicate term frequency and they may be arranged in usage or alphabetical order. Their application as a concept management tool conforms to the findings that tag clouds are strong indicators of social collaborative activity [7]. Research has shown that users scan rather than read tag cloud lists.

Figure 1: Tag Cloud using Many Eyes

Figure 1 shows a user-generated tag cloud using Many Eyes (http://manyeyes.alphaworks.ibm.com/manyeyes/), a web-based visualization tool created by International Business Machines (IBM). The cloud is organized alphabetically and represents text from Tim O'Reilly's online definition of Web 2.0. Different font sizes and colored text indicate term frequency. The text is visually unenclosed and users may immediately identify dominant concepts. When the user mouses-over the terms or clicks upon them, a pop-up box

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appears that lists term occurrences and the phrase in which the term appears. The tag cloud may be searched and subsequently the search term is enlarged and accompanied by frequency counts and context phrase information. Many Eyes also offers a 2-word tag cloud which shows word phrases in the cloud which provides a slightly augmented textual context to obtain concept clarity.

Collaborative structuring is facilitated by generating clouds from collaborative documents or creating a cloud which is derived from a social tagging structure that encompasses multiple users. In the latter structure, the collaborative group is not defined specifically for members to interactively manage the concepts for development purposes. Adapting tag clouds for concept organization in collaborative work offers advantages and disadvantages for group users. It can accommodate non-expert use and allow users to view tagged material that is relevant to the project. Terms may influence uniform adoption to provide consistent terminology among group members. It is an efficient visualization in that cooperative users may glance at or browse the cloud to quickly discern significant concepts about the topic [15,6]. Object size (e.g. words), draws upon the human capability of preattentive processing where an enlarged object among a group of distracters can be identified by users within milliseconds [19].

The conceptual organization component is not well supported in tag clouds since their primary feature is an alphabetical arrangement. If group users generate the tag cloud based on their contributions, then the collaboration may become unbalanced since an individual's concepts may be subject to greater frequency counts and visibility within the cloud. The tag cloud is devoid of dating and idea progression and cross-term relationships among the terms are not evident. Tags may be generated from the users' contributions, however research has shown that if the tags are linked to documents, then document occlusion may occur when they are accessed by users and the inclusion of supplemental links in a tag cloud remains an area for further exploration.

B. Node-link Diagrams

Node-link diagrams overcome the tag cloud's deficiency in exhibiting multiple connections among shared ideas and uses shapes, such as boxes or ellipses, to enclose concepts. The node link diagram is used in several examples such as visualizing search results generated by the Amazon recommendation algorithm in the Java-based TouchGraph tool [10] or social network diagrams which connect social groups of people. Nodes are represented by shapes whose color, size, and position on the screen may indicate hierarchical conceptual prominence (e.g. Level 1 concepts, Level 2 concepts and so forth). Lines are used to establish relationships among the nodes and if a process, such as concept development, is depicted, then unilateral and bilateral arrows may be included to provide visual navigation cues [16,19]. A simple node-link diagram is shown in Figure 2 that was generated by the online collaborative tool, bubbl.us (www.bubbl.us).

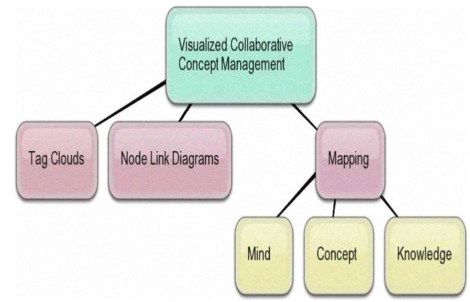

Figure 2: A Node-Link Diagram Using bubble.us

Node link diagrams offer collaborative users the means to organize concepts in sequential or hierarchical order (parent-child relationships). Relationships among the entities are clearly visualized with lines indicating connected relationships. Below the top level node are derivative sub-concepts which support the networking of concepts according to their topic contribution. Sibling concepts are visualized by their position within the diagram. In bubbl.us, the nodes may be colored, re-arranged, and linked. Collaboration is facilitated by using the "collaboration" option which permits others to edit the diagram. Sharing is permitted by adding "friends" to view the diagram. In regard to concept management, color or node size may be used to visualize concept frequency or recently updated concepts.

The node-link diagram accommodates several levels of ideas in a visual manner, but does not facilitate adding comments or creating "aunt" or "uncle" nodes where one node may be connected to their sibling's child node. Technically, the lack of cross-referencing in a node-link diagram may be analogous to a mind map, which builds upon a central concept. As group membership increases, the resulting node occlusion may generate visual clutter in the visualization. However, this issue is not limited to one type of visualization.

Another web-based option in node link diagramming is gliffy.com (www.gliffy.com). Collaboration is facilitated by blogging and sharing diagrams. The premium account offers a user management option. Gliffy is more similar to Microsoft's desktop Visio product and contains different sets of shapes for different diagrams such as flowcharts and floor plans. The structure is clear and the edit dates are exhibited upon logging into the system by viewing the "last modified" dates. Annotation is not available and another communication tool, such as a blog, may be used to coordinate collaborative communication.

C. Mapping Structures

Mapping draws upon node-link structures for establishing concept location and guiding navigation in abstract structures. Similar to node-link diagrams, general mapping uses enclosed nodes, lines, and offers a standard tree structure that is built around a central node. Physical maps are used for route planning in geographic locations. Site maps are used to

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structure web sites and to assist users in navigating information by finding their "location" in an online environment. Mapping abstract information requires a certain set of visualization features to clarify semantic term relationships and to demonstrate connectivity among concepts.

Researchers have distinguished between mind maps, concept maps, and knowledge maps. All of these share components with node-link diagrams and the terminology is not consistently applied. Knowledge visualization and maps aim to improve communication among more than two people and enhance the creation of knowledge in groups [2]. Concept maps offer the representation of ideas across nodes and meaning is inferred from their relationships [17].

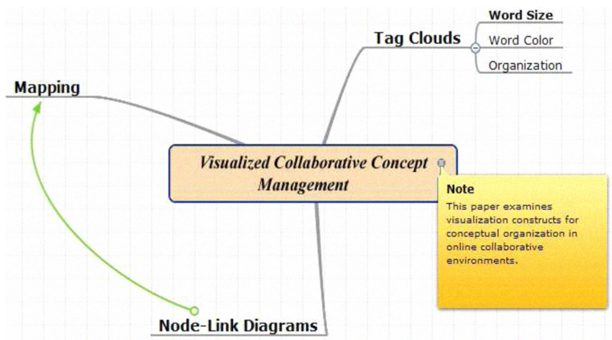

Figure 3: A Map Structure Using Mindmeister.com

In the distributed web environment, Mindmeister (www.mindmeister.com) is an example of a tool that supports collaborative brainstorming with an organized visual structure. With this tool, users are able to collaboratively organize and deposit their ideas into nodes and initiate the planning process by creating, managing, and sharing mind maps online. Unlike the node-link diagram, the brainstorming mode allows synchronous, distributed group participants to simultaneously work on the same mind map and observe co-participant's changes as they occur. This mind map offers an annotation feature and lines may be drawn to relate concept nodes. New ideas can be incorporated and linked to existing nodes. The optimization of this tool would include an indication of user counts or frequency of annotations with a visual means of ascertaining user updates. Dominant concepts should emerge from the collaborative process to allow the structuring of ideas through the group collaboration.

IV. CONCLUSIONS

The web tool analysis provides insight into identifying several features which are fundamental to collaborative concept management. A summary of the comparison is made in Table 1. It was found that visualized structures depict perception oriented overviews of concepts that may be applied during the collaborative process (Table 1: Item 7). The visualizations are browsing oriented and can draw upon users' perceptual abilities to determine color and size pop-outs. If group users devise pop-out features in the node-link diagram and the mapping tool, then the display's perceptual utility increases its organizational value for progressive group work.

The visualization rendered is dependent upon recognizing the balance between the system and the user. The tag cloud examined through Many Eyes allows user control over content to generate the structure, however the visual encoding of terms are automatically system generated (See Table 1: Items 3,4,5). Similarly, the tag cloud has an automatic default for encoding node relationships, whereas node-link diagrams and map-based visual structures allow users to change spatial properties, line colors, and connections to build a dynamic structural visualization (Table 1: Item 6).

The mapping tool is the only visual structure that conforms to social communication and collaboratory concept development by including a notes feature for detailed participant annotation (Table 1: Item 1). Sharing the visualization is possible through all three structures (Table 1: Item 11) and collaboration features are different among the three. The tag cloud can use pre-made collaborative user work to supply Many Eyes with content to generate the cloud. Many Eyes also offers members the ability to create a topic center to post comments. Other interested users may join the topic center and this represents a self selected method of sharing ideas (Table 1: Item 9). The node-link diagram offers an asynchronous structure where users can alternately use the tool to develop the collaborative visual structure. The mapping tool offers a synchronous collaboration through the brainstorming option by providing real time collaboration (Table 1: Item 12).

Tag clouds are reportedly accessible to novices due to the ease of inserting data into an automatic tool. Node-link and mapping presentations can accommodate novice to expert group users depending on the intricacy of concept representation. For concept building purposes, collaborators are well served with the node-link diagram and mapping tools since they enable a user feeling of control over creating and rearranging nodes to foster participation in the collaborative process. The level of user expertise for each visual structure needs to be examined through further research.

Table 1: Visualization Feature Comparison

Visualization Tool Feature	Tag Cloud	Node Link	Mind Map
1. Annotation Notes	Limited	x	√
2. Change Node Display	x	√	√
3. Change Node Text Color	x	√	√
4. Encoding Node Color	Auto	√	√
5. Encoding Node Size	Auto	√	√
6. Encoding Node Relationships	x	√	√
7. Perception Oriented	√	√	√
8. Obtain Concept Frequency	√	x	x
9. Add "Friends"	x	√	√
10. Show Date Modifications	x	√	√
11. Sharing	√	√	√
12. Collaboration	Limited	√	√

x= feature not available √ = available feature

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process management. While the tag cloud created through Many Eyes highlights creation dates, the mapping structure and the node-link examples offers an indirect means of checking date/time information by checking the "last modified" date upon logging into the system and viewing a publicly available mind map (Table 1: Item 10). Communication is provided by means of sharing, adding "friends", or distributing the visualizations to group members or embedding them in a blog for additional group communication (Table 1: Item 9). The visualized structures used in this analysis were primarily examined for their functional abilities in a state of reduced visual complexity.

A. Design Considerations

Following this analysis, several considerations emanate from the list of visualized features in Table 1. First, design observations derived from this analysis include:

- Integrating communication seamlessly in a visualized concept management structure and developing the option of automatic notification when changes are made (such as in wikis).
- Manipulating nodes by aligning color changes within the node or in the labeling text with the users' activities including updating or annotating concept nodes which may correspondingly change color or darken in color as they are updated or annotated.
- Acknowledging progressive group concept development requires immediate recognition along with the standard time/date stamp to increase group awareness of each other's contributions is useful in this context. This suggested feature aligns with user study work on GroupMind [14].
- Incorporating visual animation or other pop-out features while creating the display may draw users' attention to significant occurrences in the concept development process.

Second, a preliminary sketch of the initial design considerations for a collaborative visualization interface is shown in Figure 4. This display represents a web-based tool to support asynchronous distributed group work for structuring collaborative concepts to support concept organization. The design shows a visual stacking interface where concepts are boxed within rounded polygonal nodes and stacked vertically or horizontally upon one another by group users. For example, the concepts "perception" and "cognition" are horizontally stacked upon the "information visualization" node in Figure 4. Stacking collaborative concepts is unlike the more formal stacked displays or dimensional stacking which embed coordinate systems within one another [9]. This approach is analogous to generating adjacent bubbles or grouping cards of a similar suit and presenting them as stacks on the table to card game participants. The interface uses a familiar graphical design environment to optimize the end user's ease of use in learning a visualization tool for structuring collaborative concepts.

Representation. Since multiple users are the target audience, annotation frequency (the number of times group users create comments about a concept) is an important value that is visually encoded by the nodes. Group users' annotation frequency is reflected by the node's border line thickness such as the thick orange line surrounding the concept "perception" (Figure 4). Similarly, the connecting lines between concepts will thicken as more users click on the lines to visually denote agreement regarding concept relationships. The connection between two or more concepts such as the bilateral line between the "information visualization" and "data visualization" in Figure 4 demonstrates this encoding.

Recognizing line thickness draws upon the collaborators' preattentive processing capabilities to immediately recognize salient concepts and connections within the structure. Line thickness is used as a pop-out mechanism to make the relationships between nodes visually recognizable by users upon accessing the display. The mouse pointer in Figure 4 indicates a node click which activates the "Comments" box. Comments may also be accessed through the command button. A double-click on the node allows the user to insert comments. Time stamps, user names, and the number of comments are included within the annotations to show progressive concept development as indicated in Figure 4's "Comments" box.

Interaction. Collaborative interactivity is facilitated by the user creating concept nodes, stacking concept nodes in the display (that draw upon the notion of "building" a foundational structure for the resulting project), writing annotations, drawing line arcs between related concepts, and writing comments. Collaborative tasks may be allocated on the basis of examining the users' gravitation to annotating particular nodes. This aids group and concept management tasks since users associated with their annotations on particular concepts self organize and can pursue specialized collaborative work group. Users may change the location of concept nodes. Related nodes may be repositioned or new connections can be established.

Presentation. Positioning nodes is significant to generating the visualization. The interaction elements in this preliminary design are balanced between the group users and the system. If users insert new concept nodes between two or more existing nodes as shown by the dashed box "New Concept" in Figure 4, then the display readjusts the node alignment by using a spring-embedding algorithm. This is a graph layout technique that preserves the displayed node connections while one is repositioned [22]. The algorithm potentially supports the display arrangement which is user driven. For example if the user wishes to insert the "New Concept" node between the "Distortion" and "Zoom/Pan" nodes, the latter two nodes would be automatically pushed apart and the nodes would not lose their existing connections, but be rearranged algorithmically. Similarly, the process applies in removing concept nodes. Testing the algorithmic layout mechanism for compatibility with collaborative building is required.

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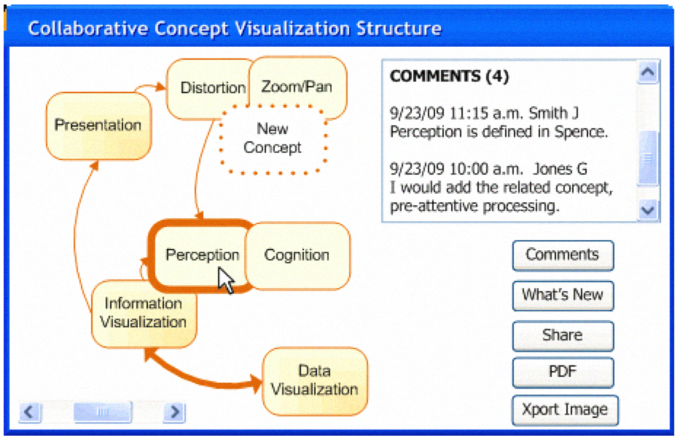

Figure 4: A Preliminary Collaborative Concept Interface Design

Additional Features. As described earlier, the Comments button activates the comments box in the display. The What's New button lists the changes made to the visual structure including all the new nodes and their annotations/comments since the user last visited the collaborative workspace. This supports the suggestion made in [13]. Sharing features and group participant lists will be embedded within the design. Consideration will be given to sharing features, blogs, and automatic update notification features to enhance group communication. A PDF (Portable Document Format) command button will be included to allow users to see or to print a discursive document of the concepts and all their annotations. Further, related concepts will be presented as links at the bottom of each concept to allow users to explore associated ideas. The incorporation of hyperlinks in the annotations offers supplemental material to substantiate concepts. The Xport Image button will allow users to export the visualization in common JPG, GIF, PNG, and other image formats to insert into documents and presentations. Overall, these preliminary ideas provide an amalgamation of previous designs used in this analysis and the anticipated user needs for using a visualization tool to structure group concepts.

B. *Future Work*

This initial analysis of visualized structures will be expanded to a larger group of tools available. Group concept design features which are identified will be extended to a new visualization-based interface to facilitate a structuring process for collaborative conceptual development. Examining visual complexity and scalability in a collaborative concept structure is required since online collaboration is dependent upon multiple users and the frequency of their concept contributions and comments. Future work includes the collaborative concept tool design refinement and developing a prototype for user testing, which can include case studies or laboratory-based user evaluation. Additional research may include determining the group users' collaborative effectiveness by implementing a three dimensional concept visualization that contains rotating nodes (cubes) where each plane represents a concept attribute such as group users, resources, and so forth.

Another planned line of research is to examine the feasibility of using visualization structures for concept development in a mobile context. A step in this direction has been taken by Mindmeister with the availability of a mobile mind map on their iPhone or iPod touch (http://blog.mindmeister.com). Screen size is at premium for visualization on mobile devices and for the preliminary design in this paper a small subset of features will be selected for the initial implementation [11]. While this is challenging, future user testing will show if a visual picture in a mobile view can convey collaborative structures effectively on small screen devices. Mobile access is ubiquitous and migration to the mobile world for collaborative activities provides momentum for developing and testing visualization structures to organize location independent participatory user concepts.

Overall this paper contributes uniquely to exploring the use of visualization tools for the structuring of collaborative concepts. It demonstrates that web tools representing visual structures do exist for public use and a combination of their current features can be used to create a visually active collaborative concept structuring process as demonstrated in the preliminary interface design. This structured visualization approach may not only enrich the collaborative process to foster more productive research, but also it may help to propel information visualization to a mainstream technology in the collaborative environment.

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