Do Four Eyes See Better than Two? Collaborative versus Individual Discovery in Data Visualization Systems

Gloria Mark, Alfred Kobsa, Victor Gonzalez
Department of Information and Computer Science
University of California, Irvine
{gmark, kobsa, vmgyg}@ics.uci.edu

Abstract[1]

We present an empirical study investigating collaborative and individual decision-making about data using two different information visualization systems. Based on previous research, one system is considered more transparent than the other in terms of visual representation and functionality. We found that people who worked in groups were more correct in their answers for objective questions, based on searching a large dataset. These results held for the more transparent system, but not the less transparent system. In a second task, groups were more accurate in their results for a free data discovery task. Again, these results held for the more transparent system only. Subjects using this system also produced results that were higher in complexity but judged lower in importance. Groups and individuals did not differ. We suggest that given the right visualization system, groups do better than individuals in finding more accurate results, but not necessarily increased or more meaningful results.

1. Introduction

A fairly large number of collaborative visualization environments have been deployed to date, to support learning, communication and discovery in groups (see e.g., CoVis [7], Cspray [14], CVD and Cave6D [9], TIDE [16], iScape [4], COVISA [21], and several prototypes of DIVA [17] and [5]. A tacit assumption underlying these systems is that learning, communication and discovery will improve when performed collaboratively.

Indeed, the development of these systems coincides with an increasing trend of collaboration in organizations, with people working both collocated and remote from each other [13]. In addition, organizations are becoming more distributed [6], which is leading to new forms of collaboration and new technologies to support them.

The intent of this paper is to investigate whether and how collaborative and individual decisions about information differ when different information visualization systems are used. We have specifically chosen to study two forms of collaboration that are common in organizations today: collocated and remote collaboration. We also selected two information visualization systems with different characteristics, according to previous research [8]. We expected that these systems would have different effects on group performance.

1.1. Collaborative and individual reasoning about data

Reasoning from visual information is a complex task, and there are several rationales to suggest that such reasoning might be done differently by groups and individuals. First, evidence suggests that the quality or accuracy of a problem solution depends on the appropriateness of the external problem representation [2, 11, 18]. Individual differences in the representation of problems, displays, and data have been well-documented (e.g. [3]). Individual differences in problem-solving are also well-known (e.g. [12]). Yet when people are in a group, a problem representation may be appropriate for one person, but not for another. In this case, the group needs to negotiate a common representation.

A second difference concerns the coordination cost of working in a group. Group members need to make various decisions at all phases of a collaborative decision-making process. They must choose roles (e.g. who will operate the system), they need to decide on a common strategy, and they need to interpret the results.

We expect many other differences to exist as well. To give some examples, a group's pace may be limited by its

[1] This research was supported by the National Science Foundation under grant no. 9729843, by the Center for Research on Information Technology and Organizations (CRITO), and by instrument grants from Smart Technologies Inc, humanIT AG and Spotfire Inc. We would like to thank Jeffrey Cheng, Cristina Gena and David Lim for helping with the experiments and their evaluation.

slowest member. In contrast, the so-called "Eureka problems" are known to be solvable by the group in the time that the quickest group member finds a solution [10]. There can be status or social effects in the group that determine which decisions will be made. A person who is deemed the expert can also affect the process.

1.2. Visualization systems used in this study

In this experiment, we have chosen two different visualization systems to examine group and individual differences: InfoZoom (formerly Focus [19, 20]) and Spotfire (formerly IVEE [1]).[2] InfoZoom presents data in three different views. The *wide view* shows the current data set in a table format, with rows representing the attributes and columns the objects. *The compressed view* compresses the visualization horizontally to fit the window width. Numeric data values are thereby plotted as horizontal cell-wide bars whose distance from the row bottom corresponds to their values. A row may be sorted in ascending or descending order, with the values in the other rows being rearranged accordingly to make each column represent one object. This operation reveals dependencies between characteristics (like positive or negative correlations between numeric attributes). Hierarchical sorting of two or more attributes is possible as well and can, e.g., reveal differences in the distribution of numeric attributes in dependence of one or more non-numeric attributes). In the *overview mode,* the values in the rows become detached from their objects. Rows here represent the value distributions of attributes in ascending or descending order, and are independent of each other. In all three views, values of (identical adjacent) attributes become textually, numerically or symbolically displayed whenever space permits this, which facilitates the comprehensibility of the data [8].

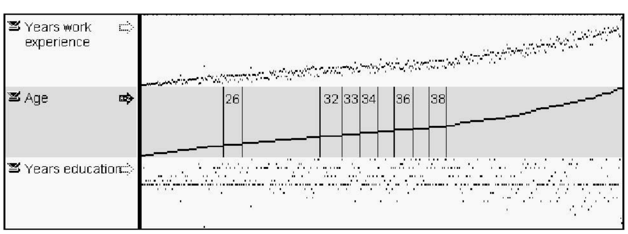

Fig. 1: InfoZoom's compressed view (gray datapoints blackened for better reproduction)

Fig. 1 shows portions of a population survey in InfoZoom's compressed mode. The individuals are sorted by age in ascending order (the database contains adults only). We see that the years of work experience are highly correlated with age since their values increase in roughly the same slope as age. In contrast, there is only a loose relationship between age and years of education. Many people of all ages have a high school education, which becomes visible as a faint horizontal line. There is a higher frequency of older people than younger people with less than 12 years of education.

InfoZoom's central operation is “zooming” into information subspaces by double-clicking on attribute values, or sets/ranges of values. InfoZoom thereupon shows records only that contain the specific attribute value(s). InfoZoom also allows one to define new variables that are functionally dependent on one or two existing ones, to highlight extreme values, and to create a variety of charts (mostly for reporting purposes).

Spotfire offers several types of mostly familiar visualizations, including scatterplots, bar charts, pie charts, graphs, parallel coordinates, trellises, etc. Unlike in InfoZoom, they are interactive primary visualizations between which the user can switch with ease. For each visualization, two variables can be selected in pulldown menus for display in the x and y coordinates, and a few additional variables through a dialog window. Focusing on information subspaces is performed by excluding or including attribute values using sliders, checkboxes and radio buttons.

Fig. 2 shows two bar charts in Spotfire that represent average hourly wages, which are higher for union members than for non-members. Filtering people by their residence (by checking and unchecking the property "Live in South?") reveals that this salary difference between union members and non-members is more distinct in the South.

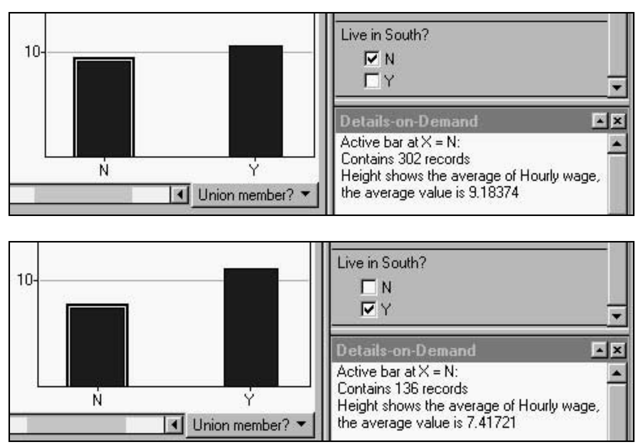

Fig. 2: Bar chart visualization in Spotfire

In a prior study reported in [8], we found that Spotfire imposes fairly high "cognitive setup costs": users took considerable time to choose among the different visualizations that Spotfire offers and to set them up correctly,

[2] The software versions used were InfoZoom 3.40 EN Professional from humanIT AG (www.humanIT.com) and Spotfire DecisionSite 6.3 from Spotfire, Inc. (www.spotfire.com).

1093-9547/02 $17.00 © 2002 IEEE

particularly when solutions included several variables and therefore several steps. This seems to be due to the fact that a significant portion of the data and the system's functionality is not immediately visible and directly accessible. Each different visualization that Spotfire offers displays relatively few variables only, and setting up a visualization requires accessing a fairly complex "properties" menu. Users must plan in advance what variables to use and how to visualize them. Since selecting visualizations for the first one or two variables imposes severe restrictions on how the remaining variables can be visualized, the upfront planning must be very thorough and comprehensive to avoid dead ends. This planning moreover must be performed without assistance from a visualization and takes considerable time.

Users of InfoZoom, in contrast, can rely much more often on visual cues when accessing both data and system functionality. (The only major exceptions are the dialog windows for defining new "derived" variables and for the charting function, both of which violate the otherwise relatively straightforward "click on what you want" paradigm.) As we saw in video recordings of the prior study, users therefore interact very effortlessly with the system. They can also plan incrementally, i.e. perform a few steps, see how far they have come, and proceed or switch to a different view if the partial plan turned out to be wrong (some users even developed a "click first - think afterwards" problem solving behavior). InfoZoom can therefore be regarded as more transparent than Spotfire, where transparency refers to the system's quality to invoke an easy-to-understand system image in users [15].

Taking this notion of transparency of systems into account, along with the differences described earlier with group and individual problem solving, we have developed the following hypothesis: the higher planning efforts required by the less transparent system Spotfire would lead to more coordination overhead in a group situation, which would negatively impact the group performance.

2. The Experiment

Subjects. One hundred undergraduate students with majors in Information and Computer Science or Engineering at the University of California, Irvine participated in the experiment. Subjects qualified for the experiment if they had at least one year of computer usage. They received $25 for their participation and competed for a $100 prize for the best results in the discovery task of the experiment.

Experimental Tasks. We chose two distinct types of tasks to test, namely a focused question task and an open-ended discovery task, as we expected that the group coordination required by these task types may be different. The first task asked subjects to use anonymized data from an online dating service to answer ten specific questions, such as: "Did males cheat more on their girlfriends than females on their boyfriends?" This problem resembles a "Eureka problem" in that the problem has only one correct answer that is immediately recognizable once it is located on the information display. In the second task, subjects were given 40 minutes and instructed to discover as many findings in the data of a population survey as they could.[3] The second task is free-form, and no specific background knowledge is required to comprehend the data. Subjects would need to make decisions as to whether a finding was relevant, unlike the first task where only one correct finding exists and is (presumably) realized as correct once it is seen.

Measures. In the first task, we measured the correctness of responses based on subjects' written answers on paper. In the second task, we measured the number, accuracy, and significance of findings, also based on their written descriptions.

Experimental Design. The experiment used a two-factor between-subjects design. The factors were:

1) *System* - two factor levels:
   a) InfoZoom: subjects used the Infozoom system in both tasks.
   b) Spotfire: subjects used the Spotfire system in both tasks.

2) *Interaction type* - three factor levels:
   a) *Alone*: subjects sat at a workstation by themselves.
   b) *Remote:* subjects sat at workstations in adjacent rooms. They performed the task while interacting via Microsoft NetMeeting and a speaker phone. They used either InfoZoom or Spotfire as shared applications. Subjects did not see each other.
   c) *Shared Electronic Whiteboard*: Two subjects worked side-by-side in front of a large 60" diagonal touch-sensitive electronic Whiteboard (SmartBoard), using either InfoZoom or Spotfire.

Subjects were randomly assigned to one of the combined conditions of System and Interaction Type. In the Remote and Shared Electronic Whiteboard conditions, subjects were unacquainted with each other.

Procedure. In all conditions, subjects first received a 30-minute training on their visualization system. During the first 10 minutes of the training, subjects received a general demonstration of the main system functionality, followed by a 20-minute hands-on tutorial using six questions from an auto statistics database. Experimenters

[3] [8] describes the dating data in more detail, as well as the auto statistics data that we used for training. The free discoveries were made using the http://lib.stat.cmu.edu/datasets/CPS_85_Wages file from the CMU StatLib repository (variables were renamed to make them more meaningful). All data sets used in the experiment are available from http://www.ics.uci.edu/~kobsa/visexp/ .

verified that subjects covered all questions and, if necessary, helped answer additional questions. After the training, the subjects were familiarized with the content of the two datasets to be used in the tasks. Subjects in the Remote and Electronic Whiteboard conditions additionally practiced using these systems.

The first experimental task (focused questions) took 30 minutes and the subsequent free discovery task took 40 minutes. Subjects then filled in a short questionnaire and were interviewed about their experience with the system.

3. Results

In general, subjects had little difficulty using the systems to perform the tasks (this was also confirmed by their responses in the final questionnaire). They also easily adjusted to the usage of NetMeeting and the Smartboard. We present the results for the focused question task first.

Task 1. In the first task, coders counted the correct number of responses out of ten questions, based on verifying correctness beforehand. Table 1 shows the mean number of correct responses, by condition.

Table 1: Mean and standard deviation of correct responses to ten questions in the first task.

Interaction \ System	InfoZoom	Spotfire	Total
Alone	6.8 (1.7)	6.7 (1.6)	6.8 (1.6)
Remote	8.4 (1.0)	7.2 (2.1)	7.8 (1.7)
Electronic Whiteboard	8.0 (2.0)	6.7 (1.2)	7.4 (1.8)
Groups combined	8.2 (1.6)	7.0 (1.7)	7.6 (1.7)

An ANOVA shows that subjects in the InfoZoom condition answered more questions correctly, $F(1,54)=4.1$, $p<.05$. Although there was a trend towards more correct responses in both Remote and Electronic Whiteboard group conditions, it did not reach significance at the .05 level: $F(2, 54)=2.1$, $p<.1$. There was no significant interaction.

As there was no difference between the two group conditions, we combined their results to compare whether being in *any* group differed from being alone when using the systems. An ANOVA shows that being in a group (see Groups Combined in Table 1), yielded higher correct responses than working alone ($F(1,56)=3.4$, $p<.07$). Broken down by system, with InfoZoom, the responses of groups were significantly more correct than those of individuals ($F(1, 28)=5.0$, $p<.03$), while no difference was found for Spotfire.

Thus, for the focused question task, being in a group (whether remote or face-to-face) resulted in more correct responses than being alone. This difference, however, is due to using the more transparent system (InfoZoom).

We now turn to the results of the second part of the task: making discoveries with the data. One extreme outlier was eliminated from the Alone condition since the high number of responses were mostly nonsensical. Table 2 gives a summary of the findings. The column on the right shows the average of both Remote and Electronic Whiteboard conditions combined, to enable a simple individual and group contrast. Subjects in the Remote condition made the most discoveries using InfoZoom, nearly 25% more than Alone or Electronic Whiteboard. However, an ANOVA showed the difference between Interaction Types did not reach significance, $F(1,53)=1.8$, $p<.17$. This was due to the large variability within each Interaction Type condition. There was a significant difference between systems, however. Subjects using Infozoom produced significantly more findings than subjects using Spotfire, $F(1,53)=4.8$, $p<.03$. There was no significant interaction.

However, looking at the raw total of findings can be misleading. Findings can be false, and they can also be meaningless. We first verified the correctness of all findings that subjects reported, and computed the ratio of accurate findings to overall findings. An ANOVA did not reveal differences between Remote and Electronic Whiteboard, so we combined these conditions. Using combined groups, there was a significant Group by System interaction, $F(1, 55)=3.9$, $p<.05$. There were no main effects, i.e. effects of Interaction Type or System. The interaction means that groups were more accurate than individuals when using InfoZoom. With Spotfire, groups and individuals showed no difference in accuracy.

We next looked at the proportion of meaningful findings. We developed criteria of what constitutes a meaningful result. Such a result must include a comparison between variables, indicate a minimum or maximum, and/or it must have “surprise” value. For example, a result of “The average age of a male construction worker that lives in the south, and is married, is about 44 years” would not be considered a particularly meaningful finding, as this statement alone is only descriptive and not very informative. It does not contrast this result with another which would give it more meaning. On the other hand, a result like “union members earn more than other workers” would be considered meaningful as it represents a comparison. Two coders first coded sample results to calibrate themselves. They then coded the results independently, with an agreement of 95.5%. Where there was disagreement, the coders discussed each coded result until they reached agreement. Most coder discrepancies were due to oversights. An ANOVA on the proportion of meaningful results showed that the difference of System approached significance, $F(1,53)=3.5$, $p<.07$. Using Spotfire yielded more meaningful results. There was no significant effect of Interaction Type, and no interaction.

Table 2: Summary of free data discovery task. Means and standard deviations are shown.

		Alone	Remote	Electronic W'board	Groups Comb.
Mean no. of findings	**Infozoom**	14.2 (6.9)	21.10 (11.5)	13.9 (6.8)	17.5 (9.9)
	Spotfire	11.8 (4.8)	12.7 (5.8)	12.3 (5.8)	12.5 (5.6)
Correct-ness	**Infozoom**	.75 (.05)	.87 (.05)	.87 (.05)	.87 (.13)
	Spotfire	.84 (.05)	.80 (.05)	.81 (.05)	.80 (.12)
Meaning-fulness	**Infozoom**	.81 (.25)	.79 (.27)	.79 (.26)	.79 (.26)
	Spotfire	.84 (.17)	.87 (.13)	.97 (.03)	.92 (.10)
Net Pro-ductivity	**Infozoom**	23.1 (11.4)	28.5 (21.0)	20.5 (9.9)	24.5 (16.5)
	Spotfire	16.6 (8.5)	18.8 (6.9)	19.7 (8.6)	19.3 (7.6)

We also investigated the complexity of the findings. For instance, "Females with 30 or more years of work experience make less per hour ($9.47) than males with 30 or more years of work experience ($15.02)" refers to the variables of gender, years of work experience, and hourly wage. This is more complex than a simple descriptive finding of "There are 23% working in the Service sector" (one variable). We defined complexity as the number of variables involved and found that Spotfire results (mean=1.52, sd=2.0) had significantly more findings with a complexity of one variable than InfoZoom (mean=.27, sd=.52), $F(1,53)=11.8$, $p<.001$. We then computed a coarse measure of the total "net productivity" of each data discovery session by adding the number of correct and meaningful findings weighed by their complexities. An ANOVA showed a main effect of System that approached significance (InfoZoom mean=24.0, sd=4.4; Spotfire mean=18.4, sd=4.4), $F(1,53)=3.3$, $p<.08$, but no Interaction Type effect and no interaction.

4. Discussion

In this experiment, we examined the effects that different information visualization systems have on groups and individuals. We selected two systems that we considered to differ in the amount of transparency they offered, in terms of visual cues of the data and the available functionality. Our hypothesis was that groups would perform better than individuals with a more transparent system, and most of our results are consistent with this hypothesis.

To summarize our results, for the focused questions, we found that being in a group yielded higher correct responses than working on the answers individually, and using the more transparent system (InfoZoom) resulted in more correct responses than the less transparent system (Spotfire). In the free data discovery task, we found a significant Group by System interaction for accuracy of the responses. Using the more transparent system led Groups to have the most accurate responses, and Alone the least accurate responses. Yet this difference did not occur with the less transparent system (Spotfire). Using Spotfire yielded more meaningful results for all Interaction Types. Using the more transparent system (InfoZoom) led people to make more complex findings.

In the focused question task, groups — whether remote or working on a large Electronic Whiteboard — did better than individuals. We attribute this result to groups being more likely to find the correct answer than individuals. In other words, the probability of finding the correct result is the probability that the group contains one person who can find the result. Groups of two have a greater probability of finding the correct result than an individual. While not exactly Eureka problems, the problems in the focused question task resemble them closely in that there was only one correct response. Once the appropriate problem representation (i.e. visual information display) was found, the answer could be identified by anyone in the group. These results follow those of Lorge and Solomon who found groups to perform superior to individuals with Eureka problems [10].

The focused question problems can be broken down into two stages. In the first stage, the appropriate problem representation needed to be found, which involves planning. In the second stage, the answer had to be identified from this display. When we broke the results down by system, we found that they were due to the use of InfoZoom, and not Spotfire. One explanation is that with InfoZoom, there is less planning for groups in finding the appropriate problem representation. In the second stage, groups would also have a greater likelihood than individuals of finding the correct answer once the right information display was selected. A system that is less transparent, and which involves more planning, will not provide groups an advantage over individuals, which is consistent with our Spotfire results. However, a caveat is that it remains yet to be learned where the groups' superior performance occurred: in the planning, the identification stage, or even in both stages.

In our second task, we investigated free discovery of data facts. Groups were more accurate than individuals. Again, this advantage occurred with the more transparent system, InfoZoom, and not with the less transparent system, Spotfire. We interpret our results to mean that groups are more likely to locate and correct errors in their findings than individuals. In a system where the visual cues are more transparent, we would expect that the errors are easier to recognize. Four eyes are better than two for finding errors.

Spotfire users delivered more meaningful results, but InfoZoom sessions yielded a higher total “net productivity”, taking the number, complexity, and meaningfulness of all findings into account. It seems that with a transparent system, one will wind up with a higher net productivity, but will achieve this gain with quite a bit of noise (i.e. non-meaningful findings). Unfortunately groups are no better than individuals in sifting through and eliminating trivial findings.

Though our results did not yield differences between Remote and Electronic Whiteboard conditions, it is important to keep in mind that in this study we just present quantitative measures. We suspect that there are strong differences in group processes, due to the different physical proximities of the participants. Furthermore, the Electronic Whiteboard provides an immersive experience with the data. Gestures, body stance, and gaze were important features of this interaction with respect to using the system. In the remote condition, this social information is absent. To truly understand where these differences lie would involve a qualitative study of the group processes. We believe that our quantitative measures did not detect these differences and intend to investigate them using qualitative measures, e.g. video analysis, in future research. Another avenue of future research will study practice effects: it may be the case that data analysts with long-time experience with a visualization system behave very differently than newly-trained subjects.

5. Conclusions

Several collaborative information visualization systems have been developed with the intent of providing a means for viewing common data or for enabling different professions to view data. However, no one has addressed the benefits that may arise simply by bringing people together, independent of whether or not people have different backgrounds. In this experiment, our results suggest that bringing people together to view data can have benefits, but they depend heavily on the kind of visualization system used. We suggest that with a more transparent system there is less coordination overhead for groups. The main strengths of group work based on our data are that groups are better at filtering out errors in the results. Four eyes do not necessarily see more, but they see better than two eyes (particularly if they are given the right lenses, i.e. the right information visualization). A system that enables clarity in a visual representation will tap the strengths of a group in locating errors. It still remains to be seen, however, whether the same benefits could be achieved in a more cost-effective manner by having the two users work individually in a sequence: one making the findings and the other verifying them.

6. References

[1] C. Ahlberg and E. Wistrand, "IVEE: An Information Visualization and Exploration Environment", InfoVis'95, New York, NY, 1995, pp. 66-73.

[2] J. R. Anderson, *Cognitive Psychology and its Implications*. San Francisco, CA: W. H. Freeman and Co, 1980.

[3] C. L. Borgman, "Individual differences in the use of information retrieval systems: Some issues and some data." 10th International ACM Special Interest Group on Information Retrieval Conference, New Orleans, 1987, pp. 61-71.

[4] K. Börner, "A Collaborative Memory Palace for Digital Library Search Results," in *Usability Evaluation and Interface Design. Proceedings of the 2001 International Conference on Human-Computer Interaction.*, vol. 1, M. J. Smith, G. Salvendy, D. Harris, and R. J. Koubek, Eds. London: Lawrence Erlbaum, 2001, pp. 1160-1164.

[5] I. Brewer, A. M. MacEachren, H. Abdo, J. Gundrum, and G. Otto, "Collaborative Geographic Visualization: Enabling Shared Understanding of Environmental Processes", InfoVis 2000: IEEE Symposium on Information Visualization, Salt Lake City, UT, 2000, pp. 137-141.

[6] M. Castells, *The Rise of the Network Society*. Blackwell: Oxford, 1996.

[7] D. Edelson, R. Pea, and L. Gomez, "Constructivism in the Collaboratory," in *Constructivist Learning Environments: Case Studies in Instructional Design*, B. G. Wilson, Ed. Englewood Cliffs, NJ: Educational Technology Publications, 1996.

[8] A. Kobsa, "An Empirical Comparison of Three Commercial Information Visualization Systems", IEEE Symposium on Information Visualization, San Diego, CA, 2001, pp. 123-130. http://www.ics.uci.edu/~kobsa/papers/ 2001-INFOVIS-kobsa.pdf

[9] C. Lascara, G. Wheless, D. Cox, R. Patterson, S. Levy, A. E. Johnson, and J. Leigh, "TeleImmersive Virtual Environments for Collaborative Knowledge Discovery", Advanced Simulation Technologies Conference, San Diego, CA, 1999 http://evlweb.eecs.uic.edu/aej/papers/ astc99.pdf

[10] I. Lorge and H. Solomon, "Two models of group behavior in the solution of Eureka-type problems.," *Psychometrika*, vol. 20, pp. 139-148, 1955.

[11] A. Newell, "Reasoning, problem-solving, and decision processes: The problem space as a fundamental category," in *Attention and Performance VIII*, R. Nickerson, Ed.: Erlbaum, 1980.

[12] D. A. Norman, *Memory and Attention*. New York: Wiley, 1976.

[13] G. M. Olson and J. S. Olson, "Distance matters," *Human-Computer Interaction*, vol. 15, pp. 139-179, 2000.

[14] A. Pang and C. M. Wittenbrink, "Collaborative 3D Visualization with CSpray," *IEEE Computer Graphics and Applications*, vol. 17, pp. 32-41, 1997.

[15] J. Preece, Y. Rogers, and H. Sharp, *Interaction Design: Beyond Human-Computer Interaction*. New York, NY: Wiley, 2002.

[16] N. Sawant, C. Scharver, J. Leigh, A. Johnson, G. Reinhart, E. Creel, S. Batchu, S. Bailey, and R. Grossman, "The Tele-Immersive Data Explorer: A Distributed Architecture for Collaborative Interactive Visualization of Large Data-sets", 4th International Immersive Projection Technology Workshop, Ames, Iowa, 2000 http://evlweb.eecs.uic.edu/cavern/TIDE/tide_ipt2000.pdf

[17] B. Schönhage, *DIVA: Architectural Perspectives for Information Visualization*. Dissertation, Vrije Universiteit, Amsterdam, Netherlands, 2000.

[18] S. Schwartz, "Modes of representation and problem solving: Well evolved is half solved.," *Journal of Experimental Psychology*, vol. 91, pp. 347-350, 1971.

[19] M. Spenke and C. Beilken, "Discovery Challenge: Visual, Interactive Data Mining with InfoZoom – the Financial Data Set", Workshop Notes on "Discovery Challenge", 3rd European Conference on Principles and Practice of Knowledge Discovery in Databases, PKDD'99, 1999, pp. 33-38. http://fit.gmd.de/~cici/InfoZoom/Discovery Challenge/Financial.ps

[20] M. Spenke, C. Beilken, and T. Berlage, "The Interactive Table for Product Comparison and Selection", UIST 96 Ninth Annual Symposium on User Interface Software and Technology, Seattle, 1996, pp. 41-50. http://fit.gmd.de/~cici/Focus/Paper/uist96.htm

[21] J. Wood, *Collaborative Visualization*, School of Computer Studies, The University of Leeds, Leeds, England, 1998.