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Evaluating the Influence of Stereoscopy on Cluster Perception in Scatterplots

Christian van Onzenoodt, Julian Kreiser, Dominique Heer, Timo Ropinski[1]

[1]Visual Computing Group
Ulm University, Ulm, Germany
{christian.van-onzenoodt, julian.kreiser, dominique.heer, timo.ropinski}@uni-ulm.de

Abstract

Unlike 2D scatterplots, which only visualize 2D data, 3D scatterplots have the advantage of showing an additional dimension of data. However, cluster analysis can be difficult for the viewer since it is challenging to perceive depth in 3D scatterplots. In addition, 3D scatterplots suffer from overdraw and require more time for perception than their 2D equivalents. As an approach to this issue, stereoscopic rendering of three-dimensional point-based scatterplots is evaluated through a user study. In detail, participants' ability to make precise judgements about the positions of clusters was explored. 2D scatterplots were compared to non-stereoscopic 3D and stereoscopic 3D scatterplots. The results showed that performance in perception decreased when confronted with 3D scatterplots in general, as opposed to 2D scatterplots. A tendency towards an improvement of perception showed when comparing stereoscopic 3D scatterplots to non-stereoscopic 3D scatterplots.

1. Introduction

Finding clusters in scatterplots is a common task in data visualization. Whether it is to analyze the relationship between two or more discrete variates, to observe the formation of many clusters, or to find trends and correlations, scatterplots are widely used and well-known diagrams to represent data. While lots of effort has been put into the investigation of 2D scatterplots, plots with three dimensions have not been investigated deeply. Even though there are several techniques to render high-dimensional data, the quality of perception still needs to be further investigated. It has been noted that the human visual system can reliably perceive clusters, trends, and correlations in sparse 2D scatterplots [LMvW10b, LMvW10a, G*13]. Even if the density increases, techniques exist to reduce clutter in scatterplots (see Section 2).

However, when dealing with 3D scatterplots, it is often considered difficult to make precise judgements about the features of clusters. Like printed pages, common computer monitors are only able to effectively display 2D images. When viewing a static 3D diagram on such monitors, it is hard to perceive the location of a single point, let alone the expansion of a cluster, due to the incapability of perceiving depth in a 2D representation. In computer graphics, various techniques have been developed to add depth perception to 2D images, such as occlusion, shading and defocus blur [Meh13]. However, most techniques are not practical when dealing with scatterplots. In the last few years, active stereoscopic displays were developed and made available on the consumer market. By rendering two separate images and presenting them to both eyes individually, a real 3D effect can be achieved. This technique is well-known as active stereoscopic rendering by using shutter glasses. Therefore, in this paper a user study is presented to compare viewers' ability to perceive clusters in three different classes of scatterplots: 2D scatterplots, 3D scatterplots, and stereoscopic 3D scatterplots. More precisely, a set of 2D and 3D scatterplots was created. In each diagram, one cluster was marked in a different color than all other clusters (see Figures 1 and 2). Then, user experiments were performed to compare viewer's ability to make precise judgements about the location of the marked cluster in 2D scatterplots, 3D scatterplots and stereoscopic 3D scatterplots.

Among many other techniques for visualizing multivariate data, scatterplots are widely used. Although invented in the first half of the nineteenth century, scatterplots are very common when it comes to data display. In fact, between 70 and 80% of graphs used in scientific publications are scatterplots [FD05]. They are especially useful when analyzing the relationship between two or more variables. Figure 3 shows a typical 2D scatterplot featuring three different classes of data (red, blue and green).

Scatterplots are not limited to show only 2D data; in principle, arbitrary high-dimensional data can be displayed when using computer systems. In 1983, D. Asimov invented the *grand tour*, a technique to project high-dimensional data orthogonally onto some 2D subspace. It is thereby possible to view higher-dimensional data as a sequence of carefully chosen 2D scatterplots [Asi83]. Due to technical progress in the field of computer graphics, 3D scatterplots have become a major field of interest in the last few years. While

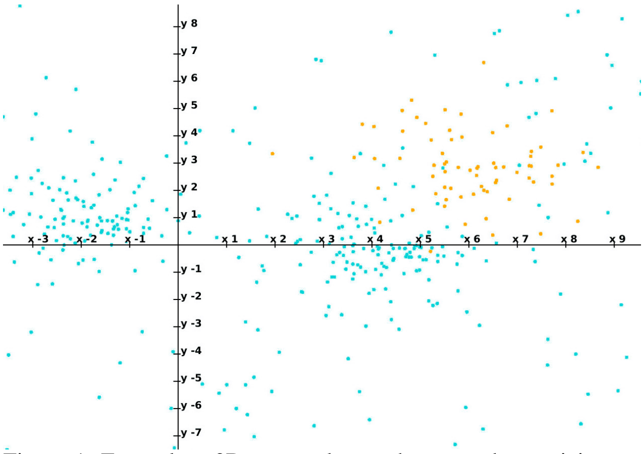


Figure 1: Exemplary 2D scatterplot as shown to the participants. The plot shows three clusters; the orange (marked) cluster has its center at $(x = 6, y = 3)$.

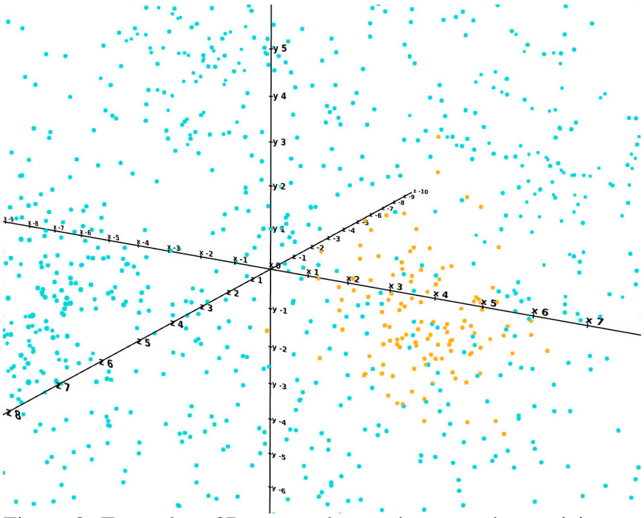


Figure 2: Exemplary 3D scatterplot as shown to the participants. The plot shows five clusters; the orange (marked) cluster has its center at $(x = 4, y = 0, z = 1)$.

showing one more data dimension, it is often difficult to perceive depth in 3D scatterplots. Therefore, a number of methods were developed and evaluated to improve depth perception in 3D scatterplots, such as illuminated scatterplots [SW09]. On the one hand, it has been shown that most techniques do indeed improve depth perception. On the other hand, these methods usually cannot compensate the absence of a third dimension.

2. Related Work

Evaluating Scatterplots. Due to the prevalence of scatterplots in scientific applications, a rich literature exists. Poco et al. [PEP*11] conducted a user study to compare point-based 3D scatterplots with surface rendering visualization techniques (such as enclosing surfaces and convex hulls), regarding viewers' performance for several tasks, such as cluster or outlier counting. They found that point-based scatterplots give a decent overall performance, however non-convex hulls were preferred most by the participants.

Based on this investigation, another study was conducted to compare viewers' performance in stereoscopic immersive environments and on a non-stereoscopic 2D screen [EML13]. A six-sided immersive virtual reality (VR) system that supports user interactions like zooming, translation and rotation was used. As with Poco's study, participants were presented various cluster visualization techniques (including point-based 3D scatterplots) and had to accomplish several tasks. As a result, surface-based techniques clearly outperformed point-based scatterplots in stereoscopic VR environments, indicating that point-based techniques are inefficient in terms of stereoscopic rendering. Even worse, the hypothesis that 3D projections in a stereoscopic VR environment improve performance on global analysis tasks (such as pattern identification) compared to a 2D screen was rejected; supposedly, this was due to the fact that many viewers had trouble maintaining the global picture when immersed in a VR environment. However, this paper further investigates this topic with special focus on point-based scatterplots.

Accordingly, Ware and Franck [WF96] explored the benefits of presenting abstract data in 3D. For this purpose, a user study was conducted to compare viewers' understanding of graphs when rendered in 2D, in 3D as a static perspective, in 3D stereo, in 3D stereo with motion cues and in 3D stereo with head coupled perspective. As in this work, active shutter glasses were used. The result indicate that stereo viewing increase the size of an abstract graph that can be understood by a factor of 1.6 and even more when head coupled 3D is used. On the other hand, motion cues are considered more significant than stereo cues. Additionally, Gleicher et al. [G*13] showed that the human visual system is able to compare average values in multiclass scatterplots efficiently and accurately, no matter how many points per class or additional distracting classes are added. For his work, he performed a large-scale perceptual study using Amazon's Mechanical Turk, a crowdsourcing Internet marketplace. Participants were not time constrained. On the other hand, Baldassi

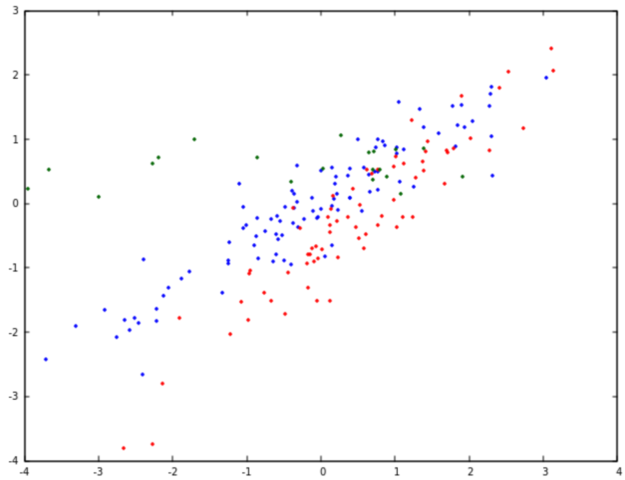


Figure 3: A common 2D scatterplot showing multivariate data, whereby red and blue depict clusters of different attributes. Similar scatterplots have been evaluated in the presented study.

et al. [BMB06] showed that perceptual decisions in dense environments can become error-prone when distracting classes are added. Participants not only submitted erroneous answers, they were also highly confident of their decisions. Scatterplots are often dense, which affects the quality of perceptual decisions. Mayorga and Gleicher [MG13] also proposed a way to overcome overdraw in scatterplots. They noted that traditional scatterplots often suffer from heavy overdraw, making it difficult for the viewer to discern data distributions and relationships among clusters. Splatterplots offer a solution by showing dense regions of points as contour-bounded filled areas and subsampling the number of points outside these areas. In addition, GPU-accelerated algorithms were implemented that make it possible to view detailed information in splatterplots by interactive navigation. Unfortunately, because of the fact that splatterplots are based on information abstraction, a loss of information is often inevitable.

Furthermore, Sips et al. [SNLH09] noted that it is often necessary to map high-dimensional data to lower-dimensional views. This is especially true for multi-dimensional scatterplots. Since mapping 3D data to 2D scatterplots can lead to a loss of information, or, even worse, to a misleading representation, it is important to represent the 3D data in such a way that a maximum of features can be perceived by the viewer. Stereoscopic rendering of 3D scatterplots as it is described in this paper is an approach to this topic. At last, Ruvalcaba [Ruv10] performed a small-scale study to determine which representation technique is most efficient to perceive clusters and outliers in high-dimensional data. They compared a single 2D scatterplot, a scatterplot matrix which shows all pairwise scatterplots of the variables in a single view, and a single 3D scatterplot. In detail, participants explored 38 different cluster and outlier tasks in random order. With each task, the participant had to identify clusters and outliers, while the computer program measured time and accuracy. As a result, the performance depended rather on the used dataset than on the representation technique. However, the study indicates that 3D scatterplots can be efficient when clusters overlap whereas 2D scatterplots benefit from well separated clusters.

Stereoscopic Rendering. Like scatterplots, stereoscopic rendering is the subject of many studies. Lo et al. [LC03] conducted user experiments to find out if stereoscopic rendering affects humans' judgement of the realism of computer-generated images. Most of the computer-generated images focus on monocular visual cues such as shading, texture gradients, relative size, occlusion and linear perspective to provide depth information. A group of participants were asked to rate the realism of rendered images, once without stereo, once with stereo vision conditions. The experiment shows that it takes considerably more time to assess the realism of a scene when it is viewed in stereo. Finally, depth cues in computer graphics have been investigated extensively. Many authors deal with the role of color as a monocular depth cue [B*07, T*91]. It has been shown that in special situations, color can play a significant role in depth perception (see Section 3.2 for more details). Accordingly, Cleveland and McGill [CM83] have run simple experiments to prove that color can cause optical illusions on statistical graphs. Various test persons were shown a red and green colored map where both regions were the same size. On average, 49% of the test persons were positive that the red region was bigger, 22% rated the green area to be bigger, and 31% were correct, that is, both regions were the same size. As a conclusion, the use of color on statistical graphs should be treated with great prudence.

Recent studies investigated the impact of stereoscopy on gaming experience. By using a Nvidia 3D Vision system equal to the one utilized in this work, Schild et al. [SLM12] performed user studies to evaluate player experience in computer games. Results showed a less thoughtful and more direct interaction with stereoscopic games.

3. Study Data Generation

The following section explains the implementation details of the software that was used to render 3D scatterplots and perform the study experiment. Subsequently, Section 4 will explain the setup of our user study, before discussing the results.

3.1. Cluster Generation

Clusters were generated by drawing a specific number of samples from a multivariate normal distribution. The density function of the latter is given by

$$f(x;\mu,\Sigma) = \frac{1}{\sqrt{(2\pi)^n|\Sigma|}}\exp(-\frac{1}{2}(x-\mu)^T\Sigma^{-1}(x-\mu))$$

with mean vector μ and covariance matrix Σ given by

$$\mu = \begin{pmatrix}\mu_1\\ \mu_2\\ \mu_3\end{pmatrix}, \Sigma = \begin{pmatrix}\sigma_{11} & \sigma_{12} & \sigma_{13}\\ \sigma_{21} & \sigma_{22} & \sigma_{23}\\ \sigma_{31} & \sigma_{32} & \sigma_{33}\end{pmatrix}$$

and a n-dimensional random variable $\mathbf{X}$, with $X \sim \mathcal{N}_n(\mu,\Sigma)$. The 3×3 covariance matrix Σ must be positive definite [Ton90].

To draw a sample from the multivariate normal distribution, the following approach was used:

1. define μ and Σ as zero vector resp. identity matrix (or any other valid vector resp. matrix as described above)
2. by using the Cholesky decomposition, find any real matrix L, such that $\Sigma = LL^T$
3. generate a vector $v = \begin{pmatrix}v_1 & v_2 & v_3\end{pmatrix}^T$, with components being independent standard normal distributed values
4. the sample $x = \begin{pmatrix}x_1 & x_2 & x_3\end{pmatrix}^T$ is now given by $x = \mu + Lv$

Steps 2-4 are repeated for every sample in every cluster.

By altering the values of the mean vector μ, it is possible to move the cluster in 3D space. Changing the values of the covariance matrix Σ leads to transformations regarding size, dilation, and rotation of a cluster. Figure 4 shows an example of such a normal distribution visualized as a 3D scatterplot.

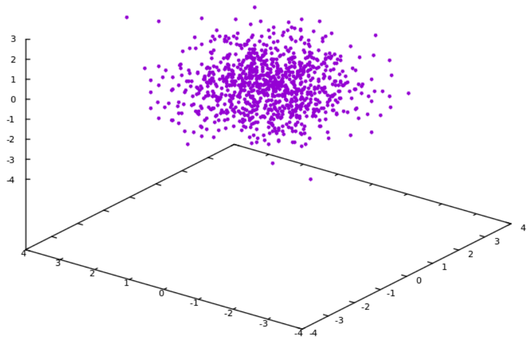


Figure 4: A plot of 100 samples drawn from a multivariate normal distribution

3.2. Cluster Rendering

A study by Bailey et al. [B*07] has shown that color can have a significant effect on the perception of depth. In particular, warm-colored objects (such as red, orange or violet) appear to be closer in depth than cool-colored objects. This effect even strengthens when the background color is dark. Therefore, the background color was chosen to be white. The marked cluser was displayed in orange, whereas the color of the distracting clusters and outliers was cyan. One advantage of these colors is, that they can be perceived by people suffering from red-green color blindness.

While color was not an overriding depth cue, relative size and occlusion was. Unfortunately, in OpenGL, points are not scaled based on their distance to the camera. In fact, the point size remains constant no matter how close or how far away points are rendered. Thus, for the 3D stimuli, a simple scaling function was implemented by using shaders, limiting the point size to 1 pixel minimum for distant points and up to 12 pixels maximum for closer points. Occlusion is simply enabled by calling *glEnable(GL_DEPTH_TEST)* and using the *GL_LESS* depth function. The camera position in 3D was set to -17.5 units into the screen; the camera rotation was set to 18° on the x-axis and -30° on the y-axis. A cartesian coordinate system was rendered with appropriate axis labels (see Figures 1 and 2). Hereby, it was ensured that all participants had the same understanding of the orientation of the coordinate system.

3.3. Active Stereoscopic Rendering

The main goal was to implement active stereoscopic rendering using shutter glasses. However, due to its simplicity and relative cheap realization, anaglyph stereo was implemented for testing purposes at first. In OpenGL, the following approach was taken:

- set up a projection matrix for the left eye
- render scene in red color by using *glColorMask(true, false, false, false)*
- set up a projection matrix for the right eye
- render scene in cyan color by using *glColorMask(false, true, true, false)*

The projection matrices for the left and right eye can be calculated by shifting the camera position and using a function like *gluLookAt* to orientate both cameras to the same focus point. This method for creating stereo pairs is known as **toe-in**. Unfortunately, it results in non-parallel projection planes for each camera.

Thus, it can be uncomfortable for the viewer to look at stereo images created with the toe-in method, especially when objects are not in the center of the screen. The solution to this problem is to use an off-axis projection, where both eyes maintain parallel view directions. Unlike the toe-in method, it requires both frustums to be non-symmetric. Objects in front of the projection plane will appear in front of the screen, whereas objects behind the projection plane will appear behind the screen.

In general, two factors influence the quality of the stereo effect: the distance between the left and the right camera referred to as *eye-separation*, and the distance between camera and projection plane (*focal length*). A common rule of thumb states that the eye-separation should be $\frac{1}{30}$ of the focal length [ZS12, p. 28].

Although the anaglyph 3D method resulted in a clearly visible stereo effect, the quality was not satisfying in terms of color and depth perception. Thus, this method was discarded in favor of active stereoscopic rendering using shutter glasses.

In order to use active stereoscopic rendering, a 3D computer monitor supporting a refresh rate of 120Hz and shutter glasses must be present. In this study, an Asus VG248QE 24 inch monitor and a Nvidia 3D Vision 2 Kit were used, the latter including wireless shutter glasses, an infrared emitter that handles the synchronization between glasses and monitor, and a software driver.

When using DirectX, Nvidia 3D Vision takes the data sent by the application to the stereo driver and renders each scene twice. The stereoscopic 3D monitor then displays the left eye view for even frames and the right eye view for odd frames [Gat09].

Unfortunately, the support of Nvidia 3D Vision for OpenGL is limited. Although the OpenGL standard does support stereo rendering by means of quad buffering, it is not implemented in the Nvidia GeForce Driver, only in the professional Nvidia Quadro Driver. Therefore, an Nvidia Quadro FX 3700 video card had to be obtained. In addition, a 3-pin mini-DIN stereo connector linked the GPU and the infrared emitter, ensuring synchronization regardless of current CPU load, which lead to a flicker-free 3D experience.

With the Nvidia Quadro graphics card, quad buffer stereo could be implemented. The projection matrices are set up following the same procedure as previously described. Again, the scene is rendered twice, once into the back left color buffer and once into the back right color buffer.

Since the application had to run at 120 frames per second minimum, special attention has been paid to optimization. However, this was not a problem since the rendered geometry was small and inexpensive.

4. User Study Setup

The following section outlines the design of the user study conducted to investigate the perceptual implications of different scatterplots. In addition, hypotheses about users' performance are formulated.

4.1. Experimental Design

The goal of the experiment was to find out to what extend stereoscopic rendering helps the viewer to perceive clusters in point-based scatterplots. Therefore, a computer program was implemented, to generate and display a set of scatterplots in randomized order. Each set consised of three types of scatterplots: 2D scatterplots, 3D scatterplots (see Figures 1 and 2), and 3D stereoscopic scatterplots, with the latter being the same as their 3D counterparts but rendered in stereo. 2D scatterplots were generated by orthographic projection from their 3D counterparts, removing the depth component. Regarding the 3D stereoscopic scatterplots, position, rotation, and size of the plots remained constant within each set, but varied between sets.

In order to validate the experimental setup, evaluate the overall 3D experience, and collect initial feedback on the 3D environment, a pilot study was carried out with three participants. The participants were undergraduate and graduate computer science students, all of whom were familiar with scatterplots. The timeout for answers was adjusted as well as the complexity of the scatterplots which were perceived (stimuli).

Following the pilot study, a second study with a larger number of participants was carried out. At the beginning of each experiment, participants were asked to fill out a questionnaire. Questions about their experience with stereoscopy and scatterplots were asked, and information about the presence of visual impairments, such as myopia, hyperopia, or red-green color blindness were gathered.

Participants were then handed the active shutter glasses and instructed to wear them permanently during the experiment. Additionally, they were asked to move their head as little as possible, to ensure the least possible difference in the viewing conditions for each stimulus. This is important since the computer display appears darker when wearing shutter glasses and the viewed image can be distorted when viewed at an angle. Furthermore, participants were instructed to work as fast as possible, as a timer was running down.

Each participant was shown a set of simple test stimuli, giving them the possibility to get accustomed to the environment. Participants who misjudged more than 50% of the 2D positions of the marked clusters, were barred from the rest of the study. However, this was never the case. In total, 30 stimuli were presented in randomized order to each participant (10 sets, each consisting of a 2D scatterplot, the same scatterplot in 3D with depth, and in 3D with depth and stereoscopy). Each of these sets consised of four sparse and six dense scatterplots. The computer program randomly chose one of the axis (X, Y or Z in 3D; X or Y in 2D) and generated three answer options for the position, one of which was correct (see Figure 5). The participant was then asked to assess the center of a cluster marked by color.

By using this method, the problem of giving the exact position of a cluster was simplified by choosing between three possible answers, demanding as little effort as possible.

Participants had to choose an answer within 25 seconds, giving them enough time to examine the scatterplot. The time limit was set, since studies have shown that participants are able to rapidly judge multi-class scatterplots, but tend to take more time for it [LMvW10b, LMvW10a, EML13]. Furthermore, the study was designed to examine the correctness of participants' choices rather than the time they needed to decide. However, when they did not respond within the 25 seconds limit, the stimulus was skipped.

At the end of each experiment, participants were asked whether they think their depth perception improved when scatterplots were rendered in stereo.

4.2. Hypotheses

It is hypothesized that the overall performance is best with 2D scatterplots and worst with 3D scatterplots; we hypothesize further that stereoscopic rendering should be located inbetween these two.

The hypothesis is supported by various studies [PEP*11, EML13]. An investigation showed that stereoscopic 3D displays can improve spatial perception for tasks that are multi-dimensional in nature, tasks that are difficult and unfamiliar, and tasks that lack other spatial visual cues [ML14]. However, as mentioned before, point-based scatterplots did not perform as well as other visualization techniques when rendered in stereoscopic 3D. Additionally, binocular disparity may not necessarily be the decisive depth cue. Hence, the following hypotheses are formulated:

H1 Performance will be lower with 3D scatterplots when compared to 2D scatterplots.
H2 Performance will be lower with 3D non-stereoscopic rendering when compared to 3D stereoscopic rendering.
H3 Overall performance will be higher when perceiving sparse scatterplots when compared to dense scatterplots.

While hypotheses H1 and H2 are concerned with performance in regards to stereoscopic rendering, hypothesis H3 addresses the issue of the perception of dense and sparse scatterplots. In this case, dense scatterplots are diagrams which show more than one class and at least 50 distracting points, while sparse ones show either one or two clusters without any noise or a single cluster with a maximum of 100 distracting points.

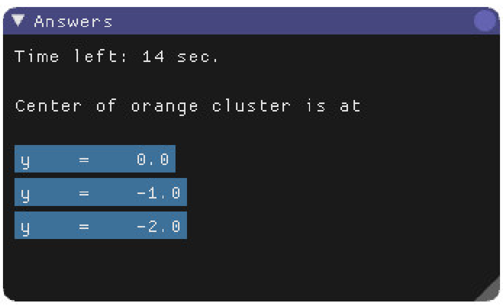
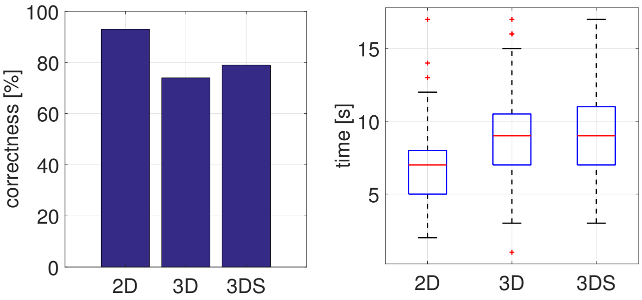
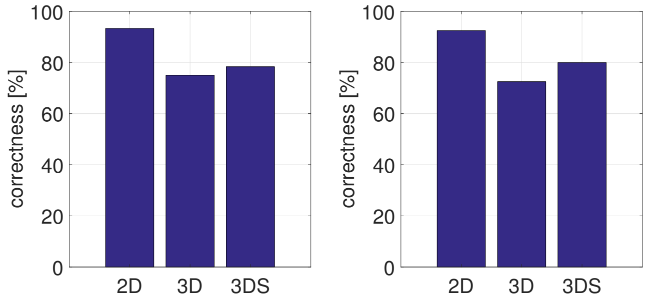


Figure 5: GUI showing an example for the answer options presented to the study subjects.



(a) Mean Correctness (b) Time Measurement

Figure 6: Performance of participants grouped by stimuli (2D, 3D and stereoscopic 3D). Times were measured per stimulus.



(a) Mean Correctness (Dense) (b) Mean Correctness (Sparse)

Figure 7: Mean correctness of dense and sparse scatterplots.

5. Experiment & Discussion

In this section, the user experiments are outlined and the results are discussed on the basis of statistical values.

5.1. Experiment

The main study took place during one week in a science laboratory at our university. A total of ten students participated, all with a background in computer science. Seven participants were male, three female, the age ranged from 19 to 25. Four out of ten participants were familiar with scatterplots and had used them in a scientific context before; only four participants had experience with stereoscopy. All participants had normal or corrected-to-normal vision, none of the participants were color-blind or had achromatopsia.

Participants practiced with several sample stimuli until they felt familiar with the task. Afterwards, as described in Section 4.1, they had to assess the center of 30 clusters within a 25 seconds time limit for each stimulus. None of the participants exceeded the time limit. Each session lasted approximately ten minutes. After each session, the participants were asked whether they felt that stereoscopic vision affected their perception of depth in a positive manner.

5.2. Results

The diagrams shown in Figure 6 and 7 show the mean value of the success rate for each type of scatterplot in percent, as well as boxplots of our time measurements.

The study showed that viewers performed best with 2D scatterplots; 93% of all cluster positions were assessed correctly. Performance decreased with 3D stereo scatterplots, where 79% of the answers were correct. However, performance was worst with 3D non-stereo scatterplots; only 74% of all cluster centers were perceived correctly by participants. These results are summarized in Figure 6.

Furthermore, the results indicate that viewers tend to take more time to judge the center of a cluster in a 3D scatterplot, which was already shown by Etemadpour et al. [EML13]. However, only a minor difference could be observed between stereoscopic and non-stereoscopic 3D scatterplots. These results are also visualized in Figure 6.

Additionally, participants' performance when exposed to sparse scatterplots in comparison to dense scatterplots (plots with a higher number of clusters, and distracting classes) should be further investigated. As shown in Figure 7, stereoscopic rendering increases performance in sparse scatterplots.

Six of the participants felt that stereoscopic rendering slightly improved their ability to perceive depth, while the remaining four did not notice any effect at all.

5.3. Discussion

In this section, the results of the user study are discussed with reference to the hypotheses formulated in Section 4.2.

Even though the results are not significant, they show a tendency towards the expected differences. A study with a greater number of participants might lead to significant differences, further strengthening the support for our hypothesis.

As predicted, the perception of clusters was best in 2D scatterplots, supporting hypothesis **H1**. Most participants had no problem assessing the center of a cluster in 2D. This might be due to the fact that 2D scatterplots are easy to perceive by nature. However, the level of difficulty increased, when marked clusters had low density and a high spread. This indicates that clusters which are dense and coherent yield a better recognition rate in 2D. In addition, the number of correct answers was almost equal in dense and sparse scatterplots.

The results also support hypothesis **H2**. The user study showed that there was a subtle improvement when using stereoscopic rendering. However, the effect was less prominent, than initially suspected. This indicates that stereoscopic rendering does have an influence on the perception of clusters in scatterplots, when point-based rendering techniques are used. However, as seen in a study by Etemadpour et al. [EML13], performance should considerably increase when using surface-based techniques.

The comparison of sparse and dense scatterplots supports hypothesis **H3**. The results show better performance for sparse scatterplots, when compared to dense ones. Stereoscopic rendering seems to be especially helpful for sparse scatterplots.

It can be concluded that point-based scatterplots benefit from stereoscopic rendering, even though the effect is not as strong as initially suspected. This may be attributed to the fact that clusters rendered with point primitives are incoherent geometric objects and therefore difficult to perceive; using surface-based rendering techniques could considerably increase performance, as shown in other studies [PEP*11, EML13].

6. Conclusion

A user study was conducted to investigate the influence of stereoscopic rendering on the perception of clusters in point-based scatterplots. A typical cluster analysis task was performed by a set of participants. They were presented with 2D scatterplots, 3D scatterplots and stereoscopic 3D scatterplots. Participants had to choose the center of a cluster marked in one color from a set of three possible answers. The results indicate that stereo rendering improves performance, especially with sparse scatterplots.

While our study shows a tendency towards the expected results, our number of participants was small. Future studies with a larger number of participants could be conducted to further strengthen our hypotheses. Future work could also include a study in which additional depth cues, such as motion, or user interactions are implemented and investigated. In doing so, the effect stereo rendering has on the perception of clusters in point-based scatterplots could be further investigated. In addition, an increase in performance with stereoscopic 3D scatterplots was observed, when participants repeated the experiment. This indicates that once users are familiar with the environment, they find it less difficult to perceive clusters. Another user study could be conducted to support this hypothesis empirically. Additionally, the influence of colors on cluster perception in scatterplots could be investigated, since this has not been taken into account in our experiment.

Acknowledgment

We would like to thank Anke Huckauf for discussing the setup of the conducted user study.

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