Chapter 6

Conclusion and Future Work

This project aimed at assessing the perception of gaze-contingent displays that contain high resolution in the area of attention and a lower level of detail in the periphery. The perception of these displays was to be compared with the perception of displays rendered in full resolution. An experiment was planned using an eye tracker to collect data on eye movements while viewing gaze-contingent displays. Although this experiment could not be conducted due to time constraints, an initial experiment was conducted that provided findings to support the view that attention driven rendering can be used to decrease the computational power demanded of virtual displays without having adverse affects on the perception of the scene.

Conclusions drawn from the experiment and from the project in general are described in section 6.1. These conclusions are encouraging and support future work on this project. Some ideas for future work are outlined in section 6.2.

6.1 Conclusions

It was inferred from the initial experiment that when asked to focus at the center of the screen, most participants could notice some change in the shape of the objects in the periphery, as the image was updated from one window size of high resolution to another (the sizes being: no window size for full resolution, large window size and small window size). The use of a large or small window size was causing some distortion in the objects in the periphery and this was probably why the subjects perceived a change in the shape of these objects. However, only 17% of the subjects could point out which object was “changing shape” and in what way. Therefore it can be said that as details of the objects in the periphery could not be noticed, a distortion in their shape would not change the perception of the image. Nevertheless, this inference needs to be authenticated by further experiments that record the impact of attention driven rendering on eye movements and through an analysis of the eye movements, gauge the impact on the perception of the scene.

This experiment used only two levels of resolution; each pixel was rendered in the area of attention and every twenty fifth pixel in the periphery. To further increase the efficiency of this project, it is also important to determine what level of resolution reduction would be applicable with increasing distance from the fixation point. This is a vital area for future research on this project, also discussed in section 6.2. The goal is to simulate the multiresolutional nature of the human retina where visual resolution decreases with increasing distance from the fixation point. The explanation is that points that are fixated on are viewed with the help of the fovea which contains receptors that provide high resolution. The further the distance from the fovea, the lesser is the number of these receptors that are used and therefore the lower the resolution perceived by the eye. This idea can also be implemented to improve depth perception of the image, with resolution of the image decreasing with increasing depth. As this was found to be a vital path for the future of this project, it is going to be adopted as an honors thesis by Larissa Winey next year; she is another member of the ITR project at Mount Holyoke College.

It was hypothesized that a smaller window would cause greater degradation and therefore the perception of an image with a smaller window would be more different from that of the control image, as compared to that of an image with a larger window. Although the results indicated that a greater percentage of subjects found the image with a larger window to be more different than that with a smaller window, this result was unexpected and inconsistent with past findings, and was attributed to human errors. Moreover, the hypothesis regarding the perception of the image could not be validated with this experiment as very simple images consisting of two boxes were used. So with all levels of distortion, two boxes were always perceived. Future experiments could be conducted with more complex images to gauge the validity of this hypothesis. In addition, this experiment involved the use of only two window sizes. Future experiments could include a larger range of window sizes to determine which window size would make displays with attention driven rendering update at a high speed and make the display appear as real as a control image.

Furthermore, the experiment that was conducted did not keep consistent many factors such as, distance of the eyes from the screen and position of the head. Consequently the collection of data was prone to some minor errors. However, the finding that exact details of objects in the periphery were not noticed as the window sizes changed has provided sufficient support for future experiments to be conducted using attention driven rendering. Future experiments with the eye tracker could involve the image being updated according to the fixation point and so fast updating of the image could potentially prevent most subjects from noticing *any* difference between images that are updated. These experiments could also include a variety of window sizes, more complex images and consistent conditions through different subjects to arrive at more accurate results.

One of the most significant findings of this project was that a gaze contingent display can be updated within the typical duration of a saccade that is in the range of 30 to 50 milliseconds. This speed was reached through a series of optimizations to a simple ray tracing program. The complexity of the algorithm used was: O(I x J x S) where I x J is the size of the display screen in terms of number of pixels and S is the number of faces or surfaces in the scene. The optimizations were implemented to reduce the number of I x J and S to a minimum. The time taken to render an image was reduced radically from 1 minute 45 seconds taken to render each pixel in an image to 50 milliseconds taken to update an image.

The most important optimization that was discovered was the minimization of repetitive calculations which reduced the rendering time for a new image from 943 milliseconds to 50 milliseconds. These optimizations have provided a strong basis for future experiments using an eye tracker to be conducted as the image can now be updated in the duration of a saccade when a person is visually impaired. Consequently, an important problem of motion perception that has been encountered in related research can be avoided while the image is being updated.

This project has great potential to contribute vital results to the field of Virtual Reality. If it can be shown that rendering the pixels being attended to with full resolution and those in the periphery with lesser detail, can create images that appear as real as images with all the pixels rendered with full resolution, then future renderings could save substantially on computation time by conducting attention driven rendering.

Attention Driven Rendering is one of the first inter-disciplinary projects that have brought together the research efforts of the Computer Science and Psychology departments at Mount Holyoke College. The achievements of this project have set a foundation for future related projects at Mount Holyoke involving the collaboration of the two departments.

6.2 Future Work

Firstly, the experiment outlined in section 3.4 should be conducted and the results used to gauge the efficiency and usefulness of this project. Any faults that may occur should also be analyzed to extract ideas for improvement on this project.

Other ideas for further research involving attention driven rendering are described in the following sections.

6.2.1 Depth Perception

Future work with this project could involve determining the employment of attention driven rendering in improving depth perception of an image. The pixels that are in focus would be attached a higher resolution. Background pixels would be blurred according to how far they are from the point of view. Therefore farther objects would be blurred greater, improving the viewer's depth perception of the objects in the scene. Experimenting with different levels of low resolution in the periphery could also be tested as a possible way of making the image appear more realistic.

6.2.2 Spatial Frequency and its Impact on Peripheral Blur

There has been limited human factors research related to the production of multiresolutional images to test the behavioral impact of different peripheral resolution drop-off rates[1]. Most studies have experimented with multiresolutional images based on functions mapping different levels of retinal eccentricity to spatial frequency cut-off levels. Retinal eccentricity refers to the distance of the image reflection in the eye from the center of the retina, or viewpoint. A high spatial frequency refers to a high level of resolution as explained in section 1.2. These studies involved showing subjects a control condition image with constant high resolution compared to images where spatial frequency levels in the periphery were lowered as retinal eccentricity increased. Objective data was collected on spatial frequency cut-off levels of blur detection and on fixation durations. Subjective data was also collected based on image quality ratings by participants. However, further research is required to determine what levels of spatial frequency increase sensitivity to peripheral blur.

6.2.3 Discrete or Continuous Levels of Resolution Reduction

Another area for human factors research in the context of this project is in deciding how to produce image resolution reduction. Two possible

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[1] Reingold, Loschky, McConkie and Stampe, *Gaze-Contingent Multiresolutional Displays: An Integrative Review, Working Paper*

methods are by either using discrete levels of resolution reduction, or continuous levels where the resolution drops off gradually with distance from the area of higher resolution[2]. A major disadvantage of the discrete resolution level method as compared to the continuous resolution method is that it causes some relatively sharp resolution transitions in the image. These obvious transitions could produce perceptual problems. Continuous levels of resolution reduction, if matched to the visual resolution levels of the retina, can potentially offer large image resolution savings. However, the continuous resolution method may not be advantageous if the loss of image resolution at a certain retinal eccentricity results in perceptual difficulty. In such a case, it is difficult to detect the exact area in the visual field where image resolution has been lost as image resolution has been reduced across the entire image. Conversely, an advantage of using discrete levels of resolution level reduction is, that in the case of such a problem of retinal and image resolution mismatch it is possible to search more specifically to detect the source of the exact area of the mismatch. Limited human factors research has been conducted to determine whether discrete or continuous levels of resolution reduction should be used; therefore there is great scope for future research in this area. One of the factors that need to be taken into account in this research is the kind of images that need to be rendered. For instance, discrete levels of resolution

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[2] Reingold, Loschky, McConkie and Stampe, *Gaze-Contingent Multiresolutional Displays: An Integrative Review, Working Paper*

have been found to cause more problems with animated images than still images. This problem could be related to both texture and motion perception involved in animated images. However, the cause of the problems still remains to be researched in depth.

6.2.4 Problem of Sharp Resolution Transitions

Another area for future research related to discrete levels of resolution reduction is on how to solve the problem of sharp resolution transitions which could produce perceptual problems. One solution could be more gradual levels of blending between different resolution levels[3]. One study found small blending regions to be very distracting but larger blending rings to be less unsettling. However, another study found no difference between two different blending ring sizes in a visual search task. Yet further studies that were investigating the detection levels of peripheral image degradation, found no difference in data collected between blended versus acute multiresolutional displays. Nonetheless, the usefulness of gradual blending as a solution to the problem of sharp resolution transitions in discrete levels of resolution reduction, needs to be experimented with varying levels of blending and varying tasks to be performed by the participants (such as search task and memory recognition task conducted by Loschky and McConkie).

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[3] Reingold, Loschky, McConkie and Stampe, *Gaze-Contingent Multiresolutional Displays: An Integrative Review, Working Paper*

6.2.5 Color Resolution Reduction

One important property of the visual system that has been largely ignored in the development of gaze-contingent multiresolutional displays is the loss of color resolution with retinal eccentricity. This property of the visual system can potentially be exploited to meet the constraints of limited bandwidth and processing power in display systems. Experiments could be conducted using for instance, varying levels of hue resolution reduction in the periphery and full-color resolution in the area of attention. These experiments could be used to query what levels of hue resolution reduction were perceived by the participant and what aspects of task performance, if any, were negatively affected[4].

6.2.6 Methods of Determining the Area of Attention

Attention driven rendering could also be tested using different methods of determining the area of attention. In my project gaze tracking was used as the method to determine the area of attention, other methods that were described in greater detail in Section 2.1 were head-contingent, hand-contingent and predictive movement of the area of attention in a display. These methods could then be compared in terms of their impact on the perception and performance of a display.

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[4] Reingold, Loschky, McConkie and Stampe, *Gaze-Contingent Multiresolutional Displays: An Integrative Review, Working Paper*

6.2.7 Image Updating Delays

A key issue for future research concerns the delay in updating the area of attention in a gaze-contingent display. Studies have found two ways in which these delays can result in perceptual problems. Firstly, if the image updating does not follow soon after a saccade, then the new point of focus could initially be on a degraded region. Short delays in updating the area of attention may not be perceived because due to saccadic suppression (defined in Section 2.1) the viewer's visual sensitivity is lower at the beginning of a fixation. However, stimulus processing accelerates after about 20 to 80 milliseconds from the start of a fixation. So, longer delays may lead to perception of the degraded area. Secondly, when update delays are very long such as 70 milliseconds, and the image is updated well into a fixation, the update may cause perception of motion.

Some studies have shown that long update delays have adversely affected perception and task performance. Other studies have also found update delays to result in simulator sickness due to incorrectly perceived motion. One research experiment compared update delays ranging from 130 to 280 milliseconds. It was found that increasing levels of update delay caused increasing errors in both path following and target identification tasks. Moreover, two more recent experiments inferred that fixation durations increased with an increase in image update delays. This inference implies that perception of the image was made difficult with update delays. Therefore, although there has been some research in this area, there is a great need for future research on quantifying the impact of increasing image update delays on different perception and performance measures (such as saccades and fixations), so as to identify when and how updating delays cause problems.

References

- Anton, Howard, Elementary Linear Algebra, John Wiley and Sons, Inc. 1994
- Deffner, Gerhard, Eye Movement Recordings to Study Determinants of Image Quality in New Display Technology, J.M. Findlay et al. (Editors), 1995 Elsevier Science B.V.
- Duchowski, Andrew, Eye Tracking Techniques for Perceptually Adaptive Graphics, Clemson University, 2001
- Duchowski, Andrew, Eye-Based Interaction in Graphical Systems: Theory and Practice (Parts 1, 2, 3), Clemson University, 2000
- Fennema, C., "*Interweaving Reason, Action and Perception*", PhD Thesis, University of Massachusetts, Amherst Massachusetts, September 1991.
- Ferguson, R. Stuart, Practical Algorithms for 3D Computer Graphics, A.K. Peters, Ltd. 2001
- Glassner, Andrew S. (Edited By), An Introduction to Ray Tracing, Academic Press Ltd. 1989
- Grigore, Burdea and Coiffet Philippe. Virtual Reality, John Wiley & Sons, Inc. 1994

- Henderson, John M., Visual Attention and Eye Movement Control During Reading and Picture Viewing, J.M. Findlay et al. (Editors), 1995 Elsevier Science B.V.
- Hill, F.S. Jr, Computer Graphics using OpenGL, second edition, Prentice Hall, 2001
- Lindley, Craig A., Practical Ray Tracing in C, John Wiley and Sons Inc. 1992
- Loschky, Lester C. and McConkie, George W., *Investigating Spatial Vision and Dynamic Attentional Selection Using a Gaze-Contingent Multiresolutional Display*, Journal of Experimental Psychology: Applied, 2002 Vol 8: 2, 99-117
- O'Rourke, Michael, Principles of Three-Dimensional Computer Animation, W.W Norton & Company, Inc, 1995
- Pollatsek, Alexander and Rayner, Keith, The Information That is Combined Across Fixations May be Different For Static and Moving Objects, Psychological Review, 2001, 41-1/2, 75-87
- Rayner Keith and Pollatsek, Alexander, *Eye Movements and Scene Perception*, Canadian Journal of Psychology, 1992, 46:3, 342-376
- Rayner, Keith, *Eye Movements and Cognitive Processes in Reading, Visual Search, and Scene Perception,* Eye Movement Research, J.M. Findlay et al. (Editors), 1995 Elsevier Science B.V.

- Reingold, Loschky, McConkie and Stampe, *Gaze-Contingent Multiresolutional Displays: An Integrative Review, Working Paper*
- Shirley, Peter, Realistic Ray Tracing, A.K. Peters, Ltd. 2000
- Shirley, Peter, Fundamentals of Computer Graphics, A.K. Peters, Ltd. 2002
- van Diepen, Paul M.J., Peter De Graef and Gery d’Ydewalle, *Chronometry of Foveal Information Extraction During Scene Perception*, Eye Movement Research, J.M. Findlay et al. (Editors), 1995 Elsevier Science B.V.
- Wandell, Brian A. Foundations of Vision, Sinauer Press, 1995
- http://www.vr.clemson.edu/eyetracking/sigcourse
- http://www.psych.ualberta.ca/~mike/Pearl_Street/Dictionary/contents/A/attention.html
- http://www.sparknotes.com/psychology/cognitive/attention/summary.html
- http://www.cs.princeton.edu/courses/archive/spring01/cs598b/
- http://www.cs.iusb.edu/~danav/images/Virtuel/
- http://www.techfak.uni-bielefeld.de/ags/ni/index_projects.html
- http://www.xl3d.com/tutorials/Iray.htm
- http://www.vr.clemson.edu/eyetracking/sigcourse/papers/vertegaal/chi99.pdf
- http://www.cs.unc.edu/~rademach/xroads-RT/RTarticle.html

- http://www.diku.dk/~panic/eyegaze/article.html
- http://www.sci.utah.edu/stories/2002/sum_star-ray.html
- http://escience.anu.edu.au/lecture/cg/GlobalIllumination/radiosity3.en.html
- http://www.psych.utoronto.ca/~yinghua/research.htm
- http://www4.comp.polyu.edu.hk/~csgeorge/course/comp421/web/lab/lab01-1up.pdf
- http://www.dynamiclearningcenter.com/samples/ray-tracing/description.html
- http://www.cs.virginia.edu/~cs551dl/lecture4/sld034.htm
- http://medialab.di.unipi.it/web/IUM/Waterloo/node69.html
- http://www.acm.org/tog/resources/RTNews/html/rtnews2d.html#art6
- http://www.cfxweb.net/~baskuene/backface.htm
- http://www.cs.rit.edu/~jmg/cgII/slides/advraytrace.pdf
- http://graphics.stanford.edu/courses/cs348b-99/L6/Lecture6.pdf
- http://www.mtholyoke.edu/~cfennema/ITR-Project/index.htm
- http://www.cs.utah.edu/research/areas/immersive/Locomotion.html
- http://www.alleydog.com/glossary/definition.cfm?term=Fovea
- http://arch.virginia.edu/arch544/doc/rgoud2.html
- http://www-unix.oit.umass.edu/~rayner/
- http://www.cs.unc.edu/~salomon/class_projects/COMP%20236/HiddenSurface.htm