“Perceptually Modulated Level of Detail for Virtual Environments”

Martin Reddy

Doctor of Philosophy
University of Edinburgh

1997

To Frances, my Mum.

Abstract

This thesis presents a generic and principled solution for optimising the visual complexity of any arbitrary computer-generated virtual environment (VE). This is performed with the ultimate goal of reducing the inherent latencies of current virtual reality (VR) technology. Effectively, we wish to remove extraneous detail from an environment which the user cannot perceive, and thus modulate the graphical complexity of a VE with little or no perceptual artifacts.

The work proceeds by investigating contemporary models and theories of visual perception and then applying these to the field of real-time computer graphics. Subsequently, a technique is devised to assess the perceptual content of a computer-generated image in terms of *spatial frequency* (c/deg), and a model of *contrast sensitivity* is formulated to describe a user's ability to perceive detail under various conditions in terms of this metric. This allows us to base the level of detail (LOD) of each object in a VE on a measure of the degree of spatial detail which the user can perceive at any instant (taking into consideration the size of an object, its angular velocity, and the degree to which it exists in the peripheral field). Additionally, a generic polygon simplification framework is presented to complement the use of perceptually modulated LOD.

The efficient implementation of this perceptual model is discussed and a prototype system is evaluated through a suite of experiments. These include a number of low-level psychophysical studies (to evaluate the accuracy of the model), a task performance study (to evaluate the effects of the model on the user), and an analysis of system performance gain (to evaluate the effects of the model on the system). The results show that for the test application chosen, the frame rate of the simulation was manifestly improved (by four to five-fold) with no perceivable drop in image fidelity. As a result, users were able to perform the given wayfinding task more proficiently and rapidly.

Finally, conclusions are drawn on the application and utility of perceptually-based optimisations; both in reference to this work, and in the wider context.

Acknowledgements

Where do I start! And having started, where do I stop!

The past few years have been rich with experience; incurring the development of many new friends and acquaintances who have, to varying degrees and in numerous contexts, helped me along the twisting and occasionally disheartening road of research. This is my opportunity to thank all these people for their myriad contributions, suggestions, friendly ears, timely distractions, and full-fat chocolate products when I needed them most.

Firstly, thanks must go to my supervisor, Eric McKenzie, for his support and feedback throughout my period of research. Also in the department, I would like to thank many of my fellow doctoral students for their cherished comradeship, e.g. Marcus Marr, Rob Payne, Isabel Rojas, Thomas Zurek, Thomas Schreiber, and many more. In particular, I owe much to Rycharde Hawkes who had the substantial tasks of proof-reading a draft of this thesis and making sure that I went to the gym regularly (to work off the above chocolate products).

I am also deeply indebted to the members of the Psychology Dept. where I spent much of my time. Specifically, I wish to offer special thanks to Simon Rushton and Julie Harris for their expertise, comments, and encouragement on many of the issues surrounding the visual perception content of my work. Similarly, gratitude is due to Ben Watson of Georgia Tech. for his constructive feedback, and to Alina Moga of Tampere University for catalysing innovation.

Out with the work setting, I would like to offer my fondest regards to Laura Coull for her presence and energy over the last three years. I feel that my time here has been more precious as a result of our friendship. My Saturday evenings would have been much more dull (and my Sunday mornings less hazy) if my old friend Colin Howes had not dutifully dragged me off to the pub once in a while. And finally, to my family, I extend my warmest wishes and thanks; just for being there.

Thanks to you all—it's been a ball.

Declaration

I declare that this doctoral thesis was composed by myself and that the work contained therein is my own, except where explicitly stated otherwise in the text. The following articles were published during my period of research. Certain material and concepts from these publications will necessarily be presented within the body of this work.

1. Reddy, M., Watson, B., Walker, N., and Hodges, L. F. (1997). Managing Level of Detail in Virtual Environments: a Perceptual Framework. *Presence: Teleoperators and Virtual Environments*. (In Press)
2. Watson, B., Walker, N., Hodges, L. F., and Reddy, M. (1997). A User Study Evaluating Level of Detail Degradation in the Periphery of Head-Mounted Displays. *Presence: Teleoperators and Virtual Environments*. (In Press)
3. Reddy, M. (1997). The Development and Evaluation of a Model of Visual Acuity for Computer-Generated Imagery. *Technical Report ECS-CSG-30-97*. Department of Computer Science, University of Edinburgh.
4. Reddy, M. (1996). SCROOGE: Perceptually-Driven Polygon Reduction. *Computer Graphics Forum*, **15**(4):191-203.
5. Reddy, M. (1996). Incorporating Models of Early Vision Processing into Virtual Reality. *The Applied Vision Association (AVA) Annual Meeting*, 1-3 April. Department of Psychology, University of Reading. (Unpublished)
6. Reddy, M. (1996). A Measure for Perceived Detail in Computer-Generated Images. *Technical Report ECS-CSG-19-96*. Department of Computer Science, University of Edinburgh.
7. Reddy, M. (1995). A Survey of Level of Detail Support in Current Virtual Reality Solutions. *Virtual Reality: Research, Development and Application*. **1**(2):95–98.
8. Reddy, M. (1995). A Perceptual Framework for Optimising Visual Detail in Virtual Environments. *Proceedings of the FIVE '95 Conference*. Queen Mary and Westfield college, University of London, UK. pp. 189–201.
9. Reddy, M. (1995). Musings on Volumetric Level of Detail for Virtual Environments. *Virtual Reality: Research, Development and Application*. **1**(1):49–56.
10. Reddy, M. (1994). Reducing Lags in Virtual Reality Systems using Motion Sensitive Level of Detail. *Proceedings of the 2nd UK VR-SIG Conference*. Theale, Reading, UK. pp. 25–31.

(*Martin Reddy*)

Table of Contents

List of Figures

List of Tables