Applications of Visual Perception to Virtual Reality Rendering

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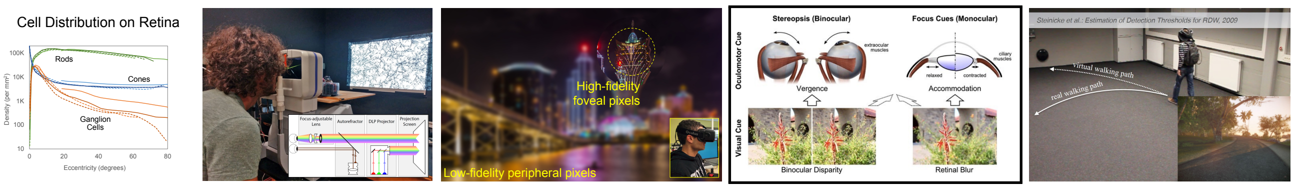

(a) Introduction to human visual perception (b) Foveated Rendering (c) Focus Cues (d) Redirected Walking

Figure 1: *Our course provides (a) an introduction to human visual perception and modern psychophysical methods, accompanied by several case studies of using perceptual insights to improve VR performance using (b) foveated rendering, addressing the vergence-accommodation conflict by providing (c) focus cues, and improving VR immersion by enabling large virtual spaces using (d) redirected walking. We also provide a forward-looking lecture identifying upcoming results and open challenges in perceptual VR.*

Abstract

Over the past few years, virtual reality (VR) has transitioned from the realm of expensive research prototypes and military installations into widely available consumer devices. But the high pixel counts and frame rates of current commodity devices more than double the rendering costs of 1920×1080 gaming, and next-generation HMDs could easily double or triple costs again. As a result, VR experiences are limited in visual quality, performance, and other capabilities. Human visual perception has repeatedly been shown to be important to creating immersion while keeping up with increasing performance requirements. Thus, an understanding of visual perception and its applications in real-time VR graphics is vital for HMD designers, application developers, and content creators.

This course begins with an overview of the importance of human perception in modern virtual reality. We accompany this overview with a dive into the key characteristics of the human visual system and the psychophysical methods used to study its properties. After laying the perceptual groundwork, we present three case studies outlining the applications of human perception to improving the performance, quality, and applicability of VR graphics. Finally, we conclude with a forward looking discussion, highlighting important future work and open challenges in perceptual VR, and a Q&A session for more in-depth audience interaction.

1 Overview

This course provides an in-depth review of perceptual methods in modern virtual reality. The instructors will introduce attendees to human visual perception, and the psychophysical methods used to study it. Then, they will present three case studies that leverage perceptual insights in improving quality, performance, and immersion of VR experiences.

• **Proposed Length**	Half day (3.25 hours)
• **Level**	Intermediate
• **Prerequisites**	Familiarity with VR/stereo graphics and modern graphics pipelines
• **Intended Audience**	Developers, researchers and students interested in mixed-reality graphics

2 Course Rationale

While researchers have long leveraged knowledge of human visual perception to improve computer graphics, recent availability of inexpensive virtual reality head-mounted displays (HMDs) has changed the landscape. For VR to succeed, extremely immersive virtual environments must be rendered within very tight computational budgets, while overcoming constraints on users' limited real-world physical space, and without causing negative health consequences like eye strain and nausea.

For the community of developers and researchers working on virtual reality, this course brings a timely collection of lectures that provide an overall perceptual understanding of the human visual system, the challenges in modern VR, and a taste of how existing and upcoming solutions use perceptual knowledge to address those challenges. We expect that our course attendees will gain an understanding of how key aspects of visual perception intersect with the design of VR hardware, software, and applications.

3 Syllabus and Talk Summaries

Table 1 provides a syllabus for the proposed course. Below we provide an overview of the topics and audience takeaways for the talks highlighted in the syllabus:

A framework for perception-driven advancement of VR systems

This talk will provide the attendees an overview of the importance of visual perception to VR. The speaker will also provide a list of open research challenges in this area, setting the stage for the following case studies.

A brief dive into human visual perception

In this talk, the speaker will provide an introduction to the basics of human visual system and the prominent psychophysical methods used to study it.

Case study: Perceptually-based foveated rendering

This talk will demonstrate the use of perceptual insights to improve the performance of eye-tracked VR graphics. The attendees will be introduced to the unique characteristics of peripheral vision, and techniques that render images targeted to peripheral vision.

Duration	Topic	Speaker
10 minutes	Welcome	Anjul Patney
30 minutes	A framework for perception-driven advancement of VR systems	Philip Robinson
30 minutes	A brief dive into human visual perception	George-Alex Koulieris
30 minutes	Case study: Perceptually-based foveated rendering	Joohwan Kim
15 minutes	Break	—
30 minutes	Case study: Incorporating focus cues into VR displays	Prof. Gordon Wetzstein
30 minutes	Case study: Redirected walking in VR	Prof. Dr. Frank Steinicke
20 minutes	Panel Q&A	All Instructors

Table 1: *Our course is designed to fit inside a half-day (3.25 hour) session, including an interative Q&A session, and a short break.*

Case study: Incorporating focus cues into VR displays

In this talk, we will discuss several solutions to the popular vergence-accommodation conflict in modern VR head-mounted displays. The speaker will provide the audience an understanding of the wide spectrum of hardware and software solutions aimed at providing focus cues to VR users.

Case study: Redirected walking in VR

In our final case study, the speaker will show how to use insights from human visual perception to create the illusion of large virtual worlds inside small physical spaces. He will cover the well known idea of redirected walking from the perspective of human perception, and provide the attendees insights on the capabilities as well as limitations of redirected walking.

4 Instructor Biographies

4.1 Instructors

Philip Robinson

Affiliation Oculus VR

Philip Robinson is a Research Scientist at Oculus VR.

George-Alex Koulieris

Affiliation Inria, Université Côte d'Azur
URL https://koulieris.com/

George-Alex Koulieris is a postdoctoral researcher at INRIA, France and visiting scholar at UC Berkeley, California, USA, working on stereo displays in collaboration with George Drettakis and Martin S. Banks. He received his PhD from the Dept. of Electronic and Computer Engineering of the Technical University of Crete (TUC), Greece, under the supervision of Katerina Mania. During his PhD thesis he worked on gaze prediction for game balancing, level-of-detail rendering and stereo grading.

Joohwan Kim

Affiliation NVIDIA Corporation
URL http://www.kimjoohwan.com

Joohwan Kim received his B.S. degree in Electrical Engineering from Seoul National University in 2003, and his Ph.D. degree in Electrical Engineering and computer science from Seoul National University in 2009. After working as a postdoctoral researcher from 2009 to 2015 at the University of California, Berkeley, he now works at NVIDIA as a Research Scientist. His research interests include visual perception, visual discomfort, and novel display and rendering technologies.

Prof. Gordon Wetzstein

Affiliation Stanford University
URL http://web.stanford.edu/~gordonwz/

Gordon Wetzstein is an Assistant Professor of Electrical Engineering and, by courtesy, of Computer Science at Stanford University. He is the leader of the Stanford Computational Imaging Lab, an interdisciplinary research group focused on advancing imaging, microscopy, and display systems. At the intersection of computer graphics, machine vision, optics, scientific computing, and perception, Prof. Wetzstein's research has a wide range of applications in next-generation consumer electronics, scientific imaging, human-computer interaction, remote sensing, and many other areas.

Prior to joining Stanford in 2014, Prof. Wetzstein was a Research Scientist in the Camera Culture Group at the MIT Media Lab. He received a Ph.D. in Computer Science from the University of British Columbia in 2011 and graduated with Honors from the Bauhaus in Weimar, Germany before that. His doctoral dissertation focuses on computational light modulation for image acquisition and display and won the Alain Fournier Ph.D. Dissertation Annual Award. He organized the IEEE 2012 and 2013 International Workshops on Computational Cameras and Displays as well as the 2917 Int. Conference on Computational Photography, founded displayblocks.org as a forum for sharing computational display design instructions with the DIY community, and presented a number of courses on Computational Displays and Computational Photography at ACM SIGGRAPH. Gordon is the recipient of an NSF CAREER award, he won best paper awards at the International Conference on Computational Photography (ICCP) in 2011 and 2014 as well as a Laval Virtual Award in 2005.

Prof. Dr. Frank Steinicke

Affiliation Universität Hamburg
URL https://www.inf.uni-hamburg.de/en/inst/ab/hci/people/steinicke.html

Frank Steinicke is a professor for Human-Computer Interaction at the Department of Informatics at the University of Hamburg. From 2011 to 2014 he was a professor of Computer Science in Media at the Department of Computer Science at the University of Würzburg and chair of the Immersive Media Group. Between 2012 and 2014 he was the director of the newly founded interdisciplinary Institute for Human Computer Media. In 2009 he assumed an associate guest professor position at the University of Minnesota.

He studied Mathematics with a Minor in Computer Science at the University of Münster, from which he received his Ph.D. and Venia Legendi in Computer Science. His research is driven by understanding the human perceptual, cognitive and motor abilities and limitations in order to reform the interaction as well as the experience in computer-mediated realities. Frank Steinicke regularly serves as panelist and speaker at major events in the area of virtual reality and human-computer interaction. He serves as the program chair for IEEE VR 2017/2018, which is the most renowned scientific conference in the area of VR/AR. He is on the IPC of various national and international conferences, and currently editor of the IEEE Computer Graphics & Applications Department on Spatial Interfaces. Furthermore, he is a member of the Steering Committee of the ACM Symposium on Spatial User Interaction (SUI) and the GI SIG VR/AR. Finally, he is a member of ACM, IEEE and GI, in particular, ACM SIGCHI, IEEE Smart Cities Community, and the GI SIGs on VR/AR, Medieninformatik and (Be-)greifbare Interaktion.

4.2 Moderator

Anjul Patney

Affiliation NVIDIA Corporation
URL https://research.nvidia.com/users/anjul-patney

Anjul Patney is a Senior Research Scientist at NVIDIA in Redmond, Washington, where he works in the area of high-performance real-time rendering. He received his M.S. and Ph.D. degrees from University of California at Davis in 2013, and his B.Tech. degree in Electrical Engineering from Indian Institute of Technology Delhi in 2007. Anjul's interests lie in the area of high-performance mixed-reality rendering, perceptual 3D graphics, and gaze-contingent rendering.