Effective User Studies in Computer Graphics

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Abstract
User studies are a useful tool for researchers, allowing them to collect data on how users perceive, interact with and process different types of sensory information. If planned in advance, user experiments can be leveraged in every stage of a research project, from early design, prototyping and feature exploration to applied proofs of concept, passing through validation and data collection for model training. User studies can provide the researcher with different types of information depending on the chosen methodology: user performance metrics, surveys and interviews, field studies, physiological data, etc. Considering human perception and other cognitive processes is particularly important in computer graphics, where most research produces outputs whose ultimate purpose is to be seen or perceived by a human. Being able to measure in an objective and systematic way how the information we generate is integrated into the representational space humans create to situate themselves in the world means that researchers will have more information to implement optimal algorithms, tools and techniques. In this tutorial we will give an overview of good practices for user studies in computer graphics with a particular focus on virtual reality use cases. We will cover the basics on how to design, carry out and analyze good user studies, as well as different particularities to be taken into account in immersive environments.
Keywords: Human-centered computing: User studies

1. Prerequisites

This course assumes a basic level understanding of issues in computer graphics and/or virtual reality. No previous knowledge of psychology, statistics or neuroscience will be assumed. All of the relevant concepts will be explained during the tutorial.

2. Tutorial outline

20 minutes: Introduction, motivation and overview

45 minutes: Good practices for user studies (Sandra Malpica)

We will first define different types of methodologies. User studies can involve a variety of metrics, such as subjective ratings, performance measures, and behavioral data, and can be conducted using generative or evaluative methodologies. We will review planning and design of experiments, how to provide clear instructions for participants, and how to select useful stimuli and observers as well as ethics in user studies. We will also share some tips to choose the appropriate statistical analysis depending on factors like required sample size or statistical power.

10 minutes: Q&A (Sandra Malpica)

45 minutes: Developing Computational Models with Mathematical and Neurological Insights. (Qi Sun)

When it comes to psychophysical studies, a wide variety of literature aims to understand the existence of correlations between stimuli and human reactions. However, in order to transform scientific discoveries into algorithmic and engineering systems, a significant gap is mathematical formulations in the continuous domain. Unlike well-labeled data for learning and regression, human psychophysical data are commonly noisy and individualized. In this lecture, we will introduce means that create human perceptual models with neurologically and physiological insights. The models are to transform into computer graphics algorithms such as shaders to predict and optimize both VR/AR system and human performance.

10 minutes: Q&A (Qi Sun)

45 minutes: Seeing in Depth (Petr Kellnhofer)

This part will explain how binocular vision and other depth cues jointly enable our 3D visual perception. We will cover concepts such as binocular disparity, ocular vergence, ocular accommodation as well as their mutual interactions. Then, we will discuss how to measure and model sensitivity of the human visual system to stereoscopic depth and how to build disparity sensitivity functions for different applications. To support this, we will also cover different types of stereoscopic displays ranging from low-cost anaglyph displays to state-of-the-art head-mounted displays and experimental display designs saturating human vision capabilities. Notably, we will describe their strengths and weaknesses and point out their suitability for different types of perceptual studies. Afterwards, we will investigate how stereoscopic vision affects our interaction with digital systems. Specifically, we will discuss the impact of correct depth reproduction on estimation of shape, absolute distance or motion of 3D objects. Furthermore, we will talk about the relation between depth in a 3D image and the perceived viewing comfort and realism. Finally, we will close the narrative loop by covering algo-

rithms exploiting these effects by utilizing perceptual models for enhancement of image qualities.

10 minutes: Q&A (Petr Kellnhofer)

45 mins: Experiencing Virtual Reality Through Embodiment (Alejandro Beacco and Gizem Senel)

Virtual Reality can be experienced either from 360 videos or real time 3D rendered environments. This part of the tutorial will show the particularities and difficulties of conducting user studies in the last, where interaction and immersion can be achieved through the embodiment of participants into virtual avatars. Concepts like body agency and body ownership, or presence, place illusion and plausibility will be introduced through a set of example, behavioral experiments and the introduction to an open source library that easily allows conducting embodiment experiments with Unity. We will then try to answer new related questions: Should questions be asked inside or outside VR? Are the classic Likert scale questionnaires outdated? Should we ask more general questions with more freedom to answer anything?

10 minutes: Q&A (Alejandro Beacco and Gizem Senel)

45 mins: Virtual characters (Rachel McDonnell)

In this part of the tutorial, the focus will be how the human is represented within virtual reality, and what effect that has on the experience. In particular, we will look at recent results on the perception of virtual humans when various geometry and material properties are altered. We will first discuss the properties of virtual humans that affect how realistic and appealing they appear, such as shape, lighting, and materials. Then, we will discuss how the choice of realistic or cartoon-like avatars can impact social interactions in immersive virtual environments.

10 minutes: Q&A (Rachel McDonnell)

45 mins: Audio in Virtual Reality (Mauricio Flores Vargas)

This part will explore the influence of auditory and audio-visual feedback in Virtual Reality. We will begin addressing the fundamentals of audio perception and sound spatialization, such as sound localization and auralization, the technical aspects of audio rendering and reproduction, and discuss the available tools and techniques and their current limitations. Additionally, we will explore the importance of audio on immersion and presence in VR and its influence on body perception as well as in physical and psychological responses. Lastly, we will examine the cross-modal effects of audiovisual feedback and how it affects both audio and visual perception in VR.

10 minutes: Q&A (Mauricio Flores Vargas)

10 minutes: Conclusions

3. Similar tutorials (EG and SIGGRAPH)

Optimizing vision and visuals - SIGGRAPH 2022

1/3rd of the course is perception. Focused on holographics displays and lenseless cameras. The perception part is about Weber's law, light and colour, sensitivity to luminance and contrast Our differentiation: focus on how to design (and implement) experiments

Authors: Koray Kavakli, David Robert Walton, Nick Antipa, Rafał Mantiuk, Douglas Lanman, Kaan Akşit

Perception of virtual characters – SIGGRAPH 2019

Perceptual research on virtual characters Our differentiation: not focused in recent results of the topic Authors: Eduard Zell, Katja Zibrek, Rachel McDonell

Applications of vision science to virtual and augmented reality – SIGGRAPH 2018-2017

Fully tailored towards VR/AR. VA conflict, HVS, eye movements and eye tracking, types of psycophysical methods, RDW case study, accomodation displays Our differentiation: more focused on how to do experiments, less in perception or VR per se Authors (different in several years): Anjul Patney, Marina Zannoli, Joohwan Kim, Robert Konrad, Frank Steinicke, Martin S. Banks, Gordon Wetzstein, George-Alex Koulieris

Computational displays - SIGGRAPH 2012

Focused in displays, light fields and perception (less than 1/3rd of the course) Our differentiation: not focused on displays but on experiments Authors: Gordon Wetzstein, Diego Gutierrez, Douglas Lanman, Matthew Hirsch

Perceptually-motivated graphics - SIGGRAPH 2010

Focused on examples of how perceptual information can be leveraged for optimizing rendering algorithms, guiding research and improving visualization. Displays, use cases, attention and memory, HVS, selective rendering Our differentiation: focused on examples of how perception can be leveraged, not on how to make user studies Authors: Ann McNamara, Katerina Mania, Marty Banks, Christopher Healey

Visual perception of 3D shape - SIGGRAPH 2009

Explores key findings of how we can perceive 3D stimuli from 2D images Different topic Authors: Roland W Fleming, Manish Singh

The whys, how tos, and pitfalls of user studies – SIGGRAPH 2009

User studies for computer graphics, case examples to demonstrate the range of the application of user studies. First part: types of studies that are appropriate at different times during development of a user-interface technique. Second part: perceived image quality and preference. Third part: eye tracking Our differentiation: this course adds the evaluation in a context of a design process (first part). Second and third parts are more similar to our tutorial, but we will have a focus in VR and newer case studies. Authors: Veronica Sundstedt, Mary Whitton, Marina Bloj

From Perception to Interaction with Virtual Characters – EG 2020

See perception of virtual characters – SIGGRAPH 2019 Authors: Eduard Zell, Katja Zibrek, Xueni "Sylvia" Pan, Marco Gillies, Rachel McDonnell

Visual Attention from a Graphics Point of View – EG 2016

Focused on eye tracking, focus on attention driven image and

video editing. Part 2: models of visual attention, emphasis on saccadic models Our differentiation: not completely focused on Eye tracking Authors: Kenneth Holmqvist, Eakta Jain, Olivier Le Meur, Sumanta N. Pattanaik

Eye tracking visualizations – EG 2014

No info Authors: M. Burch and T. Blascheck

Understanding and designing perceptual experiments – EG 2013

Detect what information humans can detect and how it is represented and processed. Basic Background on design and execution of perceptual experiments for the practicing computer scientist Authors: D. Cunningham, C. Wallraven

Computational displays – EG 2013

Same as SIGGRAPH course with Diego Gutierrez Authors: Gordon Wetzstein and D. Lanman

An eye on perceptual graphics: Eye-tracking methodology – EG 2013

How to build your own, real-time graphics, gaze-contingent displays (we don't do that). Presentation of a methodological pipeline for evaluation. Ignores HVS and focuses on technical details Authors: A. T. Duchowski, K. Krejtz, I. Krejtz, R. Mantiuk, B. Bazyluk,

Scientific evaluation in visualization – EG 2011

Planning, design, execution, analysis of results and reporting. Experimental research, hands-on trial of some methods. Authors: Camilla Forsell, Matthew Cooper

Perceptually-motivated graphics – EG 2008

HVS and how to apply it to optimization of algorithms in CG. Similar one in SIGGRAPH Authors: Katerina Mania, Erik Reinhard

4. Most relevant material

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M Slater, C Cabriera, G Senel, D Banakou, A Beacco, R Oliva, J Gallego. (2022) The Sentiment of a Virtual Rock Concert. Virtual Reality.

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Zibrek, K., McDonnell, R. (2019). Social presence and place illusion are affected by photorealism in embodied VR. In Motion, interaction and games (pp. 1-7).

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5. Presenters info

5.1. Petr Kellnhofer

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Petr Kellnhofer is an Assistant Professor in the Computer Graphics and Visualization Group at Delft University of Technology in the Netherlands. His research interests are at the intersection of computer graphics, computer vision and human perception modeling. Petr obtained his PhD at Max Planck Institute for Informatics and Saarland University in Germany in November 2016 and his thesis about perceptual modeling for stereoscopic graphical applications was awarded the Eurographics Annual Award for Best PhD Thesis in 2018. Since then, Petr has studied various aspects of human visual perception in conjunction with novel designs of head-mounted, autostereoscopic and holographic displays at MIT and Stanford University. Petr has also served as a program committee member for Eurographics and Siggraph Asia and he currently teaches university courses covering perceptual aspects of computational image processing.

5.2. Alejandro Beacco

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Alejandro Beacco is an Associate Professor in the VIRViG research group at Universitat Politècnica de Catalunya (UPC), where he received his PhD in Computer Science in 2014. His research was focused on the improvement of the simulation, animation and visualization of crowds in real-time. His knowledge in crowd animation and visualization is also extensive to 3D character animation, and 3D rendering techniques for dynamic objects or characters. From 2015 to 2022 he worked as a Post-Doc at the Experimental Virtual Environments (EVENT) Lab for Neuroscience and Technology, at Universitat de Barcelona, where he was involved in several virtual reality projects regarding medical applications, body and sports training, social interaction, recreation of historical events, and training of security forces handling crowds, among other psychological studies. Their last project involved recreating events from the past in virtual reality, with challenges such as automatically reconstructing an avatar only from an unconstrained video or pictures. During his career Alejandro also had the chance to serve the scientific community as a program committee member of IEEE VR, a panelist at IMX, and a reviewer of conferences such as MIG or journals like PlosOne. Alejandro is now back at UPC teaching computer graphics and computer animation courses.

5.3. Gizem Senel

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She was born in Istanbul in 1994. In 2012, she was awarded a full scholarship (OSYM) for her undergraduate studies at Maltepe University (Istanbul, Turkey). In 2017, she obtained a Bachelor's degree in Psychology with high honours. Between 2017-2019, she completed a Master of Science in Cognitive Neuroscience at the Brain and Cognition Master's programme at the Universitat Pompeu Fabra. Her master's thesis is titled "Behavioural and Motor Predictors of Imagination-Based Decision Making". From April to September 2019, she interned in Virtual Reality at EVENT Lab (Virtual Environments for Neuroscience and Technology), Universitat de Barcelona. During her internship, she performed data analysis for a virtual reality reinforcement learning project. She is a last-year PhD Candidate at EVENT Lab, University of Barcelona, with the INPhINIT Retaining grant from the "la Caixa" Foundation. Her research focuses on body transformation and the therapeutic applications of virtual reality. She uses Python and C as programming languages and Unity3D as the leading software in her research. She is fluent in Turkish and English and has upper-intermediate Spanish knowledge.

5.4. Rachel McDonnell

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Dr. Rachel McDonnell is an Associate Professor of Creative Technologies at Trinity College Dublin, Ireland. Her research focusses on animation of virtual characters, using perception to both deepen our understanding of how virtual characters are perceived, and directly provide new algorithms and guidelines for industry developers on where to focus their efforts. She has published over 100 papers in conferences and journals in her field, including many top-tier publications at venues such as SIGGRAPH, Eurographics, and IEEE TVCG, etc. She has served as both program and conference chair for the top venue for applied perception research – the Symposium on Applied Perception, and is on the editorial board for the associated journal ACM Transactions on Applied Perception. She also serves as an Associate Editor for Computers & Graphics, and Computer Graphics Forum, and is a regular member of many international program committees (including ACM SIGGRAPH and Eurographics).

5.5. Mauricio Flores Vargas

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Mauricio Flores Vargas is a creative arts professional with a background in sound design and music composition, interested in audio for interactive applications and technological innovations. He is completing his doctoral research at Trinity College Dublin, focused on the influence of audio and audio-visual fidelity in the perception of realism and co-presence in Virtual and Augmented Reality environments. He obtained an M.Phil. in Music and Media Technology from Trinity College Dublin in 2020 and has been developing VR and AR experiences in sonic and visual contexts that intersect artistic ideas and new means of expression using technology.

5.6. Qi Sun

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Qi Sun is an assistant professor at New York University. Before joining NYU, he was a research scientist at Adobe Research. He received his PhD at Stony Brook University. His research interests lie in perceptual computer graphics, VR/AR, computational cognition, and visual optics. He is a recipient of the IEEE Virtual Reality Best Dissertation Award, with his research recognized as Best Paper awards at ACM SIGGRAPH and IEEE ISMAR.

5.7. Sandra Malpica

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Sandra Malpica is a 4th year Ph.D. student working under the supervision of Prof. Belen Masia and Prof. Diego Gutierrez at the Graphics and Imaging Lab. She obtained her Bachelor degree at Universidad de Zaragoza, majoring in Computer Engineering (with a Computer Science mention) in 2017. Later, she obtained her Master degree at the same university, majoring in Biomedical Engineering in 2018. During 2019 and 2020 Sandra spent some months as an intern with Adobe Research and Facebook Reality Labs respectively. Those experiences allowed her to learn in new environments, improving her technical and soft skills. Sandra is interested in the particularities of human perception, and how to take advantage of those to solve current computer graphics limitations, either software- or hardware-caused. So far, her research moves around applied visual or multimodal perception in virtual reality.