# Effective User Studies in Computer Graphics: From Pixels to Perception

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**Abstract**

*User studies are essential in computer graphics and extended reality (XR), providing measurable insights into how humans perceive, interpret, and respond to visual and auditory information. When designed and executed effectively, user experiments enable researchers to validate new algorithms and interaction techniques, guide system optimization, and ensure that results align with real perceptual needs. Their role spans the entire research pipeline, from early ideation and prototyping to ecological evaluation and deployment.*

*As graphical systems increasingly rely on perceptual constraints and multimodal cues, understanding the limits and mechanisms of human perception becomes crucial. This is especially true in immersive environments, where visual quality, motion, spatial hearing, and the representation of virtual humans must all be considered to preserve comfort, realism, and performance. Systematic evaluation helps determine not only what users see, hear, or feel, but what becomes imperceptible, unnoticeable, or even attention-guiding.*

*In this tutorial, we will first introduce key principles of experimental design for user studies in computer graphics, covering methodological choices, participant management, ethics, statistical considerations, and guidelines for reporting. We will then explore how perception research directly informs cutting-edge graphics techniques across a range of sensory dimensions and XR scenarios. Talks will delve into exploiting peripheral vision for foveated rendering and attention redirection, perceptual constraints for efficient image synthesis, the role of spatial audio for immersion and interaction, the impact of virtual human appearance and embodiment, and the unique challenges of studying perception in real-world augmented reality settings.*

*Together, these perspectives provide attendees with a practical and perceptually grounded foundation to design, analyze, and apply user studies that advance both the science and technology of visual computing. (see https://www.acm.org/publications/class-2012)*

**CCS Concepts**

• ***Human-centered computing*** → ***User studies;*** *Usability testing; User models;* ***Laboratory experiments; Field studies; Virtual reality; Graphical user interfaces; Mixed / augmented reality; Displays and imagers;***

## 1. Prerequisites

This course assumes a basic level understanding of issues in computer graphics and/or extended 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

Full day tutorial.

**20 minutes: Introduction, motivation and overview**

**45 minutes: Good practices for user studies (Sandra Malpica and Daniel Martin)** We will first introduce the tutorial and give a general overview of the outline. We will then 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. Finally we will present a brief guideline on how to report results.



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**10 minutes: Q&A (Sandra Malpica and Daniel Martin)**

**45 minutes: From not visible to not noticeable to not distracting (Martin Weier)** In the first part of the talk, we will explore perceptual processes related to perceived visual quality across the visual field. While visual acuity decreases with increasing eccentricity, the eccentricity of a stimulus also impacts contrast sensitivity, chromaticity, and flicker frequency—factors critical for effectively concealing artifacts in systems such as foveated rendering. Beyond these low-level perceptual factors, task dependency further refines the adaptation of visual fidelity. The second part of the talk focuses on how to deliberately exploit these perceptual limits to guide visual attention toward points of interest. Specifically, it addresses pre-attentive visual processes to redirect gaze subtly, ideally without the user's awareness. **10 minutes: Q&A (Martin Weier)**

**45 minutes: Pushing the boundaries of efficient image synthesis for wide field of view displays. (Piotr Didyk)** Foveated rendering emerged as an essential strategy for synthesizing high-quality images for wide-field-of-view displays. Most common approaches rely on the fact that some components of generated images remain imperceptible to peripheral vision. Consequently, we can simplify image synthesis methods to avoid producing image signals that remain imperceptible. Many methods rely solely on studies of spatial perception, while neglecting that visual perception is a much richer phenomenon that includes other cues, such as motion and depth. In this talk, we will discuss several perceptual investigations of aspects of peripheral perception, including spatial and temporal resolution, motion perception, and depth perception. We will explore various study designs and discuss key factors to consider, especially when working with peripheral vision. We will then demonstrate how these perceptual experiments led to novel gaze-contingent image synthesis methods that improve computational efficiency while preserving key visual aspects of the content and ensuring or even improving user comfort. **10 minutes: Q&A (Piotr Didyk)**

**45 minutes: The Sonic Layer of Virtual Environments (Mauricio Flores-Vargas)** In this part, we explore the influence of auditory feedback as a dimension of multimodality in XR. First, we examine how sound supports perceptual constructs such as immersion and presence, contributes to perceived audio-visual fidelity, and enables meaningful interaction in Immersive Virtual Environments. Then, we focus on sound auralisation, rendering tools and techniques, and their contribution to plausible environments and virtual space representations. Finally, we highlight the importance of self-produced and embodied auditory feedback and its value for immersive applications that rely on first-person, real-time interaction. **10 minutes: Q&A (Mauricio Flores-Vargas)**

**45 minutes: 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)**

**30 minutes: Studying perception in Augmented Reality (Ernst Kruijff)** In this talk, we will explore issues that affect the performance of user studies using augmented reality headsets, specifically in outdoor conditions. We will explain the underlying perceptual processes ("perceptual pipeline"), methodologies to test various key factors, and additional measures (e.g., cognitive load) that interrelate with studying perceptual issues. A number of use cases is included to illustrate the specific issues in real-world settings. **10 minutes: Q&A (Ernst Kruijff)**

**20 minutes: Discussion and conclusions**

## 3. Presenters information

**Sandra Malpica**

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Sandra Malpica is an Assistant Professor at the University of Zaragoza, specializing in human perception and experimental methodologies in virtual reality. Her research examines how users perceive, behave, and make sense of immersive environments, with a strong emphasis on designing and conducting controlled user studies that investigate visual attention, crossmodal interactions, and performance under different perceptual demands. She has extensive hands-on experience in all phases of immersive user evaluation from experimental design to data acquisition, analysis, and interpretation, and has worked with a wide range of perceptual measures including gaze behavior, task performance, physiological indicators and subjective reporting. Sandra is passionate about translating perceptual insights into practical guidelines to improve VR systems and experiences, and regularly shares this knowledge through talks and workshops in different contexts.

**Martin Weier**

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Martin Weier is a full professor for visual computing at the Hochschule RheinMain in Wiesbaden, Germany. He received his MSc in Computer Science from the Bonn-Rhein-Sieg University Sankt Augustin and his Ph.D. from Saarland University, Germany. His research interests include perception and gaze-contingent rendering where he published a series of papers that deal with perception-driven techniques and gaze-contingent ray tracing systems in head-mounted displays. However, currently Martin's group is also investigating visual guidance and preattentive perception.

**Piotr Didyk**

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Piotr Didyk is an Associate Professor at the Università della

Svizzera italiana(USI). His research focuses on the intersection of human perception, computer graphics, image and video processing, and computational fabrication. He earned his PhD from Saarland University and the Max Planck Institute for Informatics, followed by a postdoctoral stay at MIT. Before joining USI, he was a group leader at Saarland University and a senior researcher at the Max Planck Institute. He is a recipient of an ERC Starting Grant and was elected a Junior Fellow of the European Association for Computer Graphics. He actively contributes to the academic community by participating in program committees for leading computer graphics conferences such as SIGGRAPH and Eurographics and serving as an Associate Editor for the ACM Transactions on Graphics and ACM Transactions on Applied Perception.

**Daniel Martin**

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Daniel is an assistant professor at Universidad de Zaragoza (Spain), where he got his PhD under the supervision of Prof. Belen Masia and Prof. Diego Gutierrez. His research mainly spans virtual reality and encompasses topics such as understanding and modeling visual attention and gaze behavior, multimodality, content generation, and studying diverse perceptual manipulations. During his PhD, he did two research stays at Adobe Research, one under the supervision of Dr. Xin Sun, and another one supervised by Dr. Aaron Hertzmann and Dr. Stephen DiVerdi, and one research stay at Meta Reality Labs Research, supervised by Dr. Michael Proulx. In 2024, he received the Spanish national SCIE-BBVA award for young researchers in computer science, and in 2025, the Best PhD Award from the Eurographics Spanish Chapter and a second prize for the Young Research Talents from Tercer Milenio.

**Mauricio Flores-Vargas**

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Mauricio is a fourth-year PhD student at Trinity College Dublin (Ireland) under the supervision of Dr. Rachel McDonnell and Dr. Enda Bates. His research explores audio-visual perception, spatial audio, and real-time auralisation in immersive virtual environments, with a focus on multimodal systems that use high-fidelity audio to enhance creative practice and performance. His publications in multimodal and immersive technology include contributions to IWMM (Best Student Paper Award), ISMAR, AES, and Arts Journal. He is also a creative practitioner and sound designer working at the intersection of the creative arts and XR technology.

**Ernst Kruijff**

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Ernst Kruijff is a professor for Human Computer Interaction with the Institute of Visual Computing, Bonn-Rhein-Sieg University of Applied Sciences. He is also adjunct professor with SFU-SIAT in Canada. His research has focused at the human-factors driven analysis, design and validation of multisensory 3D user interfaces. He has published widely at conferences such as IEEE VR, ISMAR and ACM CHI, and has won several awards, including the IEEE ISMAR impact award for his paper on perceptual issues in augmented reality.

**Rachel McDonnell**

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Rachel McDonnell is a Professor in Creative Technologies at the School of Computer Science & Statistics, Trinity College Dublin, and head of the Graphics and Vision Discipline. Her research focuses on real-time character animation, virtual humans, and the perceptual evaluation of motion and realism in VR and interactive media. She has published extensively in leading venues such as SIGGRAPH, Eurographics, IEEE VR/ISMAR, and ACM IVA, and has served on programme committees and editorial boards across the major graphics and VR conferences. Her work has significantly advanced understanding of how perceptual factors influence the believability and emotional impact of animated and virtual characters.

## 4. Similar tutorials (EG and SIGGRAPH)

**Effective user studies in Computer Graphics** (by a subset of the same authors, Qi Sun and Petr Kellnhofer). Euroraphics 2023, May 8 (Germany). Approximated number of attendees: 40 people.

This tutorial is an updated and expanded continuation of our 2023 course Effective User Studies in Computer Graphics. While the previous edition introduced methodological foundations and examples from vision and multimodality, this new version incorporates more recent and diverse case studies that reflect ongoing shifts in graphics and XR research.

We introduce new topics such as studying perception in augmented reality, including constraints of outdoor AR evaluation, and updated perspectives on perception-driven rendering, attention guidance, and virtual human appearance. These additions address areas that have rapidly gained importance and were not covered in the previous tutorial.

The updated case studies demonstrate how perceptual principles are now applied across a broader range of sensory dimensions and experimental contexts, enabling attendees to better translate user study best practices into cutting-edge research scenarios.

By providing refreshed content aligned with current technologies and research challenges, this new version ensures that the tutorial remains timely, relevant, and valuable for both new and returning attendees.

**Other, similar tutorials**

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 XR 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 Similar to the SIGGRAPH course with Diego Gutierrez Authors: Gordon Wetzstein, Piotr Didyk 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