

IS&T International Symposium on  
**Electronic  
Imaging**  
SCIENCE AND TECHNOLOGY

**PROCEEDINGS**

13 January 2019 – 17 January 2019 • Burlingame, CA, USA

**The Engineering Reality of Virtual Reality 2019**

Editors: Margaret Dolinsky, Indiana Univ. (United States),  
Ian E. McDowall, Fakespace Labs, Inc. (United States)

These papers represent the program of Electronic Imaging 2019,  
held January 13 – January 17, 2019, at the Hyatt Regency San Francisco Airport in Burlingame, CA.

Copyright 2019

Society for Imaging Science and Technology  
7003 Kilworth Lane • Springfield, VA 22151 USA  
703/642-9090  
703/642-9094 fax  
info@imaging.org  
www.imaging.org

All rights reserved. These proceedings, or parts thereof, may not be reproduced in any form without the written permission of the Society.

ISSN 2470-1173  
<https://doi.org/10.2352/ISSN.2470-1173.2019.2.ERVR-A02>  
Manuscripts are reproduced from PDFs as submitted and approved by authors  
no editorial changes have been made.

## The Engineering Reality of Virtual Reality 2019

### Conference overview

Virtual and augmented reality systems are evolving. In addition to research, the trend toward content building continues and practitioners find that technologies and disciplines must be tailored and integrated for specific visualization and interactive applications. This conference serves as a forum where advances and practical advice toward both creative activity and scientific investigation are presented and discussed. Research results can be presented and applications can be demonstrated.

### Highlights

This year ERVR is expanding into joint sessions on Tuesday and Wednesday. On Tuesday ERVR is co-hosting the "Visualization Facilities" joint session with Stereoscopic Displays and Applications XXX. On Wednesday morning, ERVR is co-hosting the "360, 3D, and VR" session with Stereoscopic Displays and Applications XXX. Then on Wednesday afternoon, the ERVR program includes the Light Field Imaging and Display theme day symposium session.

On Thursday the core ERVR conference sessions kick off with sessions "Going Places with VR," "Recognizing Experiences: Expanding VR," and "Reaching Beyond: VR in Translation." Finally, if you are following the EI 2019 medical imaging virtual track, note the final session in that track is the ERVR "3D Medical Imaging VR" session on Thursday afternoon.

Conference Chairs and Program Committee:  
**Margaret Dolinsky**, Indiana University (United States), and **Ian E. McDowall**, Intuitive Surgical / Fakespace Labs (United States)



# THE ENGINEERING REALITY OF VIRTUAL REALITY 2019

**Tuesday, January 15, 2019**

7:15 – 8:45 am Women in Electronic Imaging Breakfast

10:00 am – 7:00 pm Industry Exhibition

10:10 – 11:00 am Coffee Break

12:30 – 2:00 pm Lunch

## Tuesday Plenary

**2:00 – 3:00 pm**

Grand Peninsula Ballroom D

**The Quest for Vision Comfort: Head-Mounted Light Field Displays for Virtual and Augmented Reality**, Hong Hua, professor of optical sciences, University of Arizona (United States)

Hong Hua will discuss the high promises and the tremendous progress made recently toward the development of head-mounted displays (HMD) for both virtual and augmented reality displays, developing HMDs that offer uncompromised optical pathways to both digital and physical worlds without encumbrance and discomfort confronts many grand challenges, both from technological perspectives and human factors. She will particularly focus on the recent progress, challenges and opportunities for developing head-mounted light field displays (LF-HMD), which are capable of rendering true 3D synthetic scenes with proper focus cues to stimulate natural eye accommodation responses and address the well-known vergence-accommodation conflict in conventional stereoscopic displays.

*Dr. Hong Hua is a professor of optical sciences at the University of Arizona. With more than 25 years of experience, Hua is widely recognized through academia and industry as an expert in wearable display technologies and optical imaging and engineering in general. Hua's current research focuses on optical technologies enabling advanced 3D displays, especially head-mounted display technologies for virtual reality and augmented reality applications, and microscopic and endoscopic imaging systems for medicine. Hua has published more than 200 technical papers and filed a total of 23 patent applications in her specialty fields, and delivered numerous keynote addresses and invited talks at major conferences and events worldwide. She is an SPIE Fellow and OSA senior member. She was a recipient of NSF Career Award in 2006 and honored as UA Researchers @ Lead Edge in 2010. Hua and her students shared a total of 8 "Best Paper" awards in various IEEE, SPIE and SID conferences. Hua received her PhD in optical engineering from the Beijing Institute of Technology in China (1999). Prior to joining the UA faculty in 2003, Hua was an assistant professor with the University of Hawaii at Manoa in 2003, was a Beckman Research Fellow at the Beckman Institute of University of Illinois at Urbana-Champaign between 1999 and 2002, and was a post-doc at the University of Central Florida in 1999.*

3:00 – 3:30 pm Coffee Break

## Visualization Facilities

JOINT SESSION

Session Chairs: Margaret Dolinsky, Indiana University (United States) and Björn Sommer, University of Konstanz (Germany)

**3:30 – 5:10 pm**

Grand Peninsula Ballroom BC

*This session is jointly sponsored by: The Engineering Reality of Virtual Reality 2019, and Stereoscopic Displays and Applications XXX.*

3:30

SD&A-641

**Tiled stereoscopic 3D display wall – Concept, applications and evaluation**, Björn Sommer, Alexandra Diehl, Karsten Klein, Philipp Meschenmoser, David Weber, Michael Aichem, Daniel Keim, and Falk Schreiber, University of Konstanz (Germany)

3:50

SD&A-642

**The quality of stereo disparity in the polar regions of a stereo panorama**, Daniel Sandin<sup>1,2</sup>, Haoyu Wang<sup>3</sup>, Alexander Guo<sup>1</sup>, Ahmad Atrai<sup>1</sup>, Dick Ainsworth<sup>4</sup>, Maxine Brown<sup>3</sup>, and Tom DeFanti<sup>2</sup>; <sup>1</sup>Electronic Visualization Lab (EVL), University of Illinois at Chicago, <sup>2</sup>California Institute for Telecommunications and Information Technology (Calit2), University of California San Diego, <sup>3</sup>University of Illinois at Chicago, and <sup>4</sup>Ainsworth & Partners, Inc. (United States)

4:10

SD&A-644

**Opening a 3-D museum - A case study of 3-D SPACE**, Eric Kurland, 3-D SPACE (United States)

4:30

SD&A-645

**State of the art of multi-user virtual reality display systems**, Juan Munoz Arango, Dirk Reiners, and Carolina Cruz-Neira, University of Arkansas at Little Rock (United States)

4:50

SD&A-646

**StarCAM - A 16K stereo panoramic video camera with a novel parallel interleaved arrangement of sensors**, Dominique Meyer<sup>1</sup>, Daniel Sandin<sup>2</sup>, Christopher McFarland<sup>1</sup>, Eric Lo<sup>1</sup>, Gregory Dawe<sup>1</sup>, Haoyu Wang<sup>2</sup>, Ji Dai<sup>1</sup>, Maxine Brown<sup>2</sup>, Truong Nguyen<sup>1</sup>, Harlyn Baker<sup>3</sup>, Falko Kuester<sup>1</sup>, and Tom DeFanti<sup>1</sup>; <sup>1</sup>University of California, San Diego, <sup>2</sup>University of Illinois at Chicago, and <sup>3</sup>EPIImaging, LLC (United States)

5:30 – 7:00 pm Symposium Demonstration Session

**Wednesday January 16, 2019**

**360, 3D, and VR**

JOINT SESSION

Session Chairs: Neil Dodgson, Victoria University of Wellington (New Zealand) and Ian McDowall, Intuitive Surgical / Fakespace Labs (United States)

**8:50 – 10:10 am**

Grand Peninsula Ballroom BC

*This session is jointly sponsored by: The Engineering Reality of Virtual Reality 2019, and Stereoscopic Displays and Applications XXX.*

8:50

SD&A-647

**Enhanced head-mounted eye tracking data analysis using super-resolution**, Qianwen Wan<sup>1</sup>, Aleksandra Kaszowska<sup>1</sup>, Karen Panetta<sup>1</sup>, Holly Taylor<sup>1</sup>, and Sos Agaian<sup>2</sup>; <sup>1</sup>Tufts University and <sup>2</sup>CUNY/ The College of Staten Island (United States)

9:10

SD&A-648

**Effects of binocular parallax in 360-degree VR images on viewing behavior**, Yoshihiro Banchi, Keisuke Yoshikawa, and Takashi Kawai, Waseda University (Japan)

9:30

SD&A-649

**Visual quality in VR head mounted device: Lessons learned with StarVR headset**, Bernard Mendiburu, Starbreeze (United States)

9:50

SD&A-650

**Time course of sickness symptoms with HMD viewing of 360-degree videos (JIST-first),** Jukka Häkkinen<sup>1</sup>, Fumiya Ohta<sup>2</sup>, and Takashi Kawai<sup>2</sup>; <sup>1</sup>University of Helsinki (Finland) and <sup>2</sup>Waseda University (Japan)

10:00 am – 3:30 pm Industry Exhibition

10:10 – 11:00 am Coffee Break

12:30 – 2:00 pm Lunch

**Wednesday Plenary**

**2:00 – 3:00 pm**

Grand Peninsula Ballroom D

**Light Fields and Light Stages for Photoreal Movies, Games, and Virtual Reality,** Paul Debevec, senior scientist, Google (United States)

Paul Debevec will discuss the technology and production processes behind “Welcome to Light Fields”, the first downloadable virtual reality experience based on light field capture techniques which allow the visual appearance of an explorable volume of space to be recorded and reprojected photorealistically in VR enabling full 6DOF head movement. The lightfields technique differs from conventional approaches such as 3D modelling and photogrammetry. Debevec will discuss the theory and application of the technique. Debevec will also discuss the Light Stage computational illumination and facial scanning systems which use geodesic spheres of inward-pointing LED lights as have been used to create digital actor effects in movies such as Avatar, Benjamin Button, and Gravity, and have recently been used to create photoreal digital actors based on real people in movies such as Furious 7, Blade Runner: 2049, and Ready Player One. The lighting reproduction process of light stages allows omnidirectional lighting environments captured from the real world to be accurately reproduced in a studio, and has recently be extended with multispectral capabilities to enable LED lighting to accurately mimic the color rendition properties of daylight, incandescent, and mixed lighting environments. They have also recently used their full-body light stage in conjunction with natural language processing and automultiscopic video projection to record and project interactive conversations with survivors of the World War II Holocaust.

*Paul Debevec is a senior scientist at Google VR, a member of Google VR’s Daydream team, and adjunct research professor of computer science in the Viterbi School of Engineering at the University of Southern California, working within the Vision and Graphics Laboratory at the USC Institute for Creative Technologies. Debevec’s computer graphics research has been recognized with ACM SIGGRAPH’s first Significant New Researcher Award (2001) for “Creative and Innovative Work in the Field of Image-Based Modeling and Rendering”, a Scientific and Engineering Academy Award (2010) for “the design and engineering of the Light Stage capture devices and the image-based facial rendering system developed for character relighting in motion pictures” with Tim Hawkins, John Monos, and Mark Sagar, and the SMPTE Progress Medal (2017) in recognition of his achievements and ongoing work in pioneering techniques for illuminating computer-generated objects based on measurement of real-world illumination and their effective commercial application in numerous Hollywood films. In 2014, he was profiled in The New Yorker magazine’s “Pixel Perfect: The Scientist Behind the Digital Cloning of Actors” article by Margaret Talbot.*

3:00 – 3:30 pm Coffee Break

**Light Field Imaging and Display**

JOINT SESSION

Session Chair: Gordon Wetzstein, Stanford University (United States)  
Grand Peninsula Ballroom D

*This session is jointly sponsored by the EI Steering Committee.*

3:30

EISS-706

**Light fields - From shape recovery to sparse reconstruction (Invited),** Ravi Ramamoorthi, University of California, San Diego (United States)

*Prof. Ravi Ramamoorthi is the Ronald L. Graham Professor of Computer Science, and Director of the Center for Visual Computing, at the University of California, San Diego. Ramamoorthi received his PhD in computer science (2002) from Stanford University. Prior to joining UC San Diego, Ramamoorthi was associate professor of EECS at the University of California, Berkeley, where he developed the complete graphics curricula. His research centers on the theoretical foundations, mathematical representations, and computational algorithms for understanding and rendering the visual appearance of objects, exploring topics in frequency analysis and sparse sampling and reconstruction of visual appearance datasets a digital data-driven visual appearance pipeline; light-field cameras and 3D photography; and physics-based computer vision. Ramamoorthi is an ACM Fellow for contributions to computer graphics rendering and physics-based computer vision, awarded Dec. 2017, and an IEEE Fellow for contributions to foundations of computer graphics and computer vision, awarded Jan. 2017.*

4:10

EISS-707

**The beauty of light fields (Invited),** David Fattal, LEIA Inc. (United States)

*Dr. David Fattal is co-founder and CEO at LEIA Inc., where he is in charge of bringing their mobile holographic display technology to market. Fattal received his PhD in physics from Stanford University (2005). Prior to founding LEIA Inc., Fattal was a research scientist with HP Labs, HP Inc. At LEIA Inc., the focus is on immersive mobile, with screens that come alive in richer, deeper, more beautiful ways. Flipping seamlessly between 2D and lightfields, mobile experiences become truly immersive: no glasses, no tracking, no fuss. Alongside new display technology LEIA Inc. is developing Leia Loft™ — a whole new canvas.*

4:30

EISS-708

**Light field insights from my time at Lytro (Invited),** Kurt Akeley, Google Inc. (United States)

*Dr. Kurt Akeley is a distinguished engineer at Google Inc. Akeley received his PhD in stereoscopic display technology from Stanford University (2004), where he implemented and evaluated a stereoscopic display that passively (e.g., without eye tracking) produces nearly correct focus cues. After Stanford, Akeley worked with OpenGL at NVIDIA Incorporated, was a principal researcher at Microsoft Corporation, and a consulting professor at Stanford University. In 2010, he joined Lytro Inc. as CTO. During his seven-year tenure as Lytro’s CTO, he guided and directly contributed to the development of two consumer light-field cameras and their related display systems, and also to a cinematic capture and processing service that supported immersive, six-degree-of-freedom virtual reality playback.*

4:50 EISS-709  
**Quest for immersion (Invited)**, Kari Pulli, Stealth Startup (United States)

Dr. Kari Pulli has spent two decades in computer imaging and AR at companies such as Intel, NVIDIA and Nokia. Before joining a stealth startup, he was the CTO of Meta, an augmented reality company in San Mateo, heading up computer vision, software, displays, and hardware, as well as the overall architecture of the system. Before joining Meta, he worked as the CTO of the Imaging and Camera Technologies Group at Intel, influencing the architecture of future IPU's in hardware and software. Prior, he was vice president of computational imaging at Light, where he developed algorithms for combining images from a heterogeneous camera array into a single high-quality image. He previously led research teams as a senior director at NVIDIA Research and as a Nokia fellow at Nokia Research, where he focused on computational photography, computer vision, and AR. Pulli holds computer science degrees from the University of Minnesota (BSc), University of Oulu (MSc, Lic. Tech), and University of Washington (PhD), as well as an MBA from the University of Oulu. He has taught and worked as a researcher at Stanford, University of Oulu, and MIT.

5:10 EISS-710  
**Industrial scale light field printing (Invited)**, Matthew Hirsch, Lumii Inc. (United States)

Dr. Matthew Hirsch is a co-founder and chief technical officer of Lumii. He worked with Henry Holtzman's Information Ecology Group and Ramesh Raskar's Camera Culture Group at the MIT Media Lab, making the next generation of interactive and glasses-free 3D displays. Hirsch received his bachelors from Tufts University in computer engineering, and his Masters and Doctorate from the MIT Media Lab. Between degrees, he worked at Analogic Corp. as an imaging engineer, where he advanced algorithms for image reconstruction and understanding in volumetric x-ray scanners. His work has been funded by the NSF and the Media Lab consortia, and has appeared in SIGGRAPH, CHI, and ICCP. Hirsch has also taught courses at SIGGRAPH on a range of subjects in computational imaging and display, with a focus on DIY.

5:30 – 7:00 pm Symposium Interactive Papers (Poster) Session

## Thursday January 17, 2019

### Going Places with VR

Session Chair: Ian McDowall, Intuitive Surgical / Fakespace Labs (United States)

**9:10 – 10:30 am**  
 Grand Peninsula Ballroom BC

9:10 ERVR-175  
**ARFurniture: Augmented reality indoor decoration style colorization**, Qianwen Wan<sup>1</sup>, Aleksandra Kaszowska<sup>1</sup>, Karen Panetta<sup>1</sup>, Holly Taylor<sup>1</sup>, and Sos Agaian<sup>2</sup>; <sup>1</sup>Tufts University and <sup>2</sup>CUNY/ The College of Staten Island (United States)

9:30 ERVR-176  
**Artificial intelligence agents for crowd simulation in an immersive environment for emergency response**, Sharad Sharma<sup>1</sup>, Phillip Devreaux<sup>1</sup>, Jock Grynovicki<sup>2</sup>, David Scribner<sup>2</sup>, and Peter Grazaitis<sup>2</sup>; <sup>1</sup>Bowie State University and <sup>2</sup>Army Research Laboratory (United States)

9:50 ERVR-177  
**BinocularsVR – A VR experience for the exhibition “From Lake Konstanz to Africa, a long distance travel with ICARUS”**, Björn Sommer<sup>1</sup>, Stefan Feyer<sup>1</sup>, Daniel Klinkhammer<sup>1</sup>, Karsten Klein<sup>1</sup>, Jonathan Wieland<sup>1</sup>, Daniel Fink<sup>1</sup>, Moritz Skowronski<sup>1</sup>, Mate Nagy<sup>2</sup>, Martin Wikelski<sup>2</sup>, Harald Reiterer<sup>1</sup>, and Falk Schreiber<sup>1</sup>; <sup>1</sup>University of Konstanz and <sup>2</sup>Max Planck Institute for Ornithology (Germany)

10:10 ERVR-178  
**3D visualization of 2D/360° image and navigation in virtual reality through motion processing via smart phone sensors**, Md. Ashraful Alam, Maliha Tasnim Aurini, and Shiab Mushfiq-ul Islam, BRAC University (Bangladesh)

10:30 – 10:50 am Coffee Break

### Recognizing Experiences: Expanding VR

Session Chair: Margaret Dolinsky, Indiana University (United States)

**10:50 am – 12:30 pm**  
 Grand Peninsula Ballroom BC

10:50 ERVR-179  
**Overcoming limitations of the HoloLens for use in product assembly**, Jack Miller, Melynda Hoover, and Eliot Winer, Iowa State University (United States)

11:10 ERVR-180  
**Both-hands motion recognition and reproduction characteristics in front/side/rear view**, Tatsunosuke Ikeda, Mie University (Japan)

11:30 ERVR-181  
**Collaborative virtual reality environment for a real-time emergency evacuation of a nightclub disaster**, Sharad Sharma<sup>1</sup>, Isaac Amo-Fempong<sup>1</sup>, David Scribner<sup>2</sup>, Jock Grynovicki<sup>2</sup>, and Peter Grazaitis<sup>2</sup>; <sup>1</sup>Bowie State University and <sup>2</sup>Army Research Laboratory (United States)

11:50 ERVR-182  
**PlayTIME: A tangible approach to designing digital experiences**, Daniel Buckstein<sup>1</sup>, Michael Gharbharan<sup>2</sup>, and Andrew Hogue<sup>2</sup>; <sup>1</sup>Champlain College (United States) and <sup>2</sup>University of Ontario Institute of Technology (Canada)

12:10 ERVR-183  
**Augmented reality education system for developing countries**, Md. Ashraful Alam, Intisar Hasnain Faiyaz, Sheakh Fahim Ahmmed Joy, Mehedi Hasan, and Ashikuzzaman Bhuiyan, BRAC University (Bangladesh)

12:30 – 1:30 pm Lunch

### Reaching Beyond: VR in Translation

Session Chair: Ian McDowall, Intuitive Surgical / Fakespace Labs (United States)

**2:00 – 3:20 pm**  
 Grand Peninsula Ballroom BC

2:00 ERVR-184  
**Enhancing mobile VR immersion: A multimodal system of neural networks approach to an IMU Gesture Controller**, Juan Niño<sup>1,2</sup>, Jocelyne Kiss<sup>1,2</sup>, Geoffrey Edwards<sup>1,2</sup>, Ernesto Morales<sup>1,2</sup>, Sherezada Ochoa<sup>1,2</sup>, and Bruno Bernier<sup>1</sup>; <sup>1</sup>Laval University and <sup>2</sup>Center for Interdisciplinary Research in Rehabilitation and Social Integration (Canada)

2:20 ERVR-185

**Augmented cross-modality: Translating the physiological responses, knowledge and impression to audio-visual information in virtual reality (JIST-first)**, Yutaro Hirao and Takashi Kawai, Waseda University (Japan)

2:40 ERVR-186

**Real-time photo-realistic augmented reality under dynamic ambient lighting conditions**, Kamran Alipour and Jürgen Schulze, University of California, San Diego (United States)

3:00 ERVR-187

**AR in VR: Simulating augmented reality glasses for image fusion**, Fayez Lahoud and Sabine Süssstrunk, École Polytechnique Fédérale de Lausanne (EPFL) (Switzerland)

3:20 – 3:40 pm Coffee Break

---

### 3D Medical Imaging VR

---

Session Chair: Margaret Dolinsky, Indiana University (United States)

#### 3:40 – 4:00 pm

Grand Peninsula Ballroom BC

3:40 ERVR-188

**3D medical image segmentation in virtual reality**, Shea Yonker, Oleksandr Korshak, Timothy Hedstrom, Alexander Wu, Siddharth Atre, and Jürgen Schulze, University of California, San Diego (United States)

---

#### Panel Discussion: The State of VR/AR Today

---

#### 4:00 – 5:00 pm

Grand Peninsula Ballroom BC

*This session is jointly sponsored by the EI Steering Committee.*

**Panel Moderator:** Margaret Dolinsky, Indiana University (United States)

**JOIN US AT THE NEXT EI!**

IS&T International Symposium on

# Electronic Imaging

SCIENCE AND TECHNOLOGY

*Imaging across applications . . . Where industry and academia meet!*



- **SHORT COURSES • EXHIBITS • DEMONSTRATION SESSION • PLENARY TALKS •**
- **INTERACTIVE PAPER SESSION • SPECIAL EVENTS • TECHNICAL SESSIONS •**

[www.electronicimaging.org](http://www.electronicimaging.org)

