

# BREAKING THE BARRIERS TO TRUE AUGMENTED REALITY

KEYNOTE AT 23RD INTERNATIONAL DISPLAY WORKSHOP

FUKUOKA, JAPAN

7 DECEMBER 2016

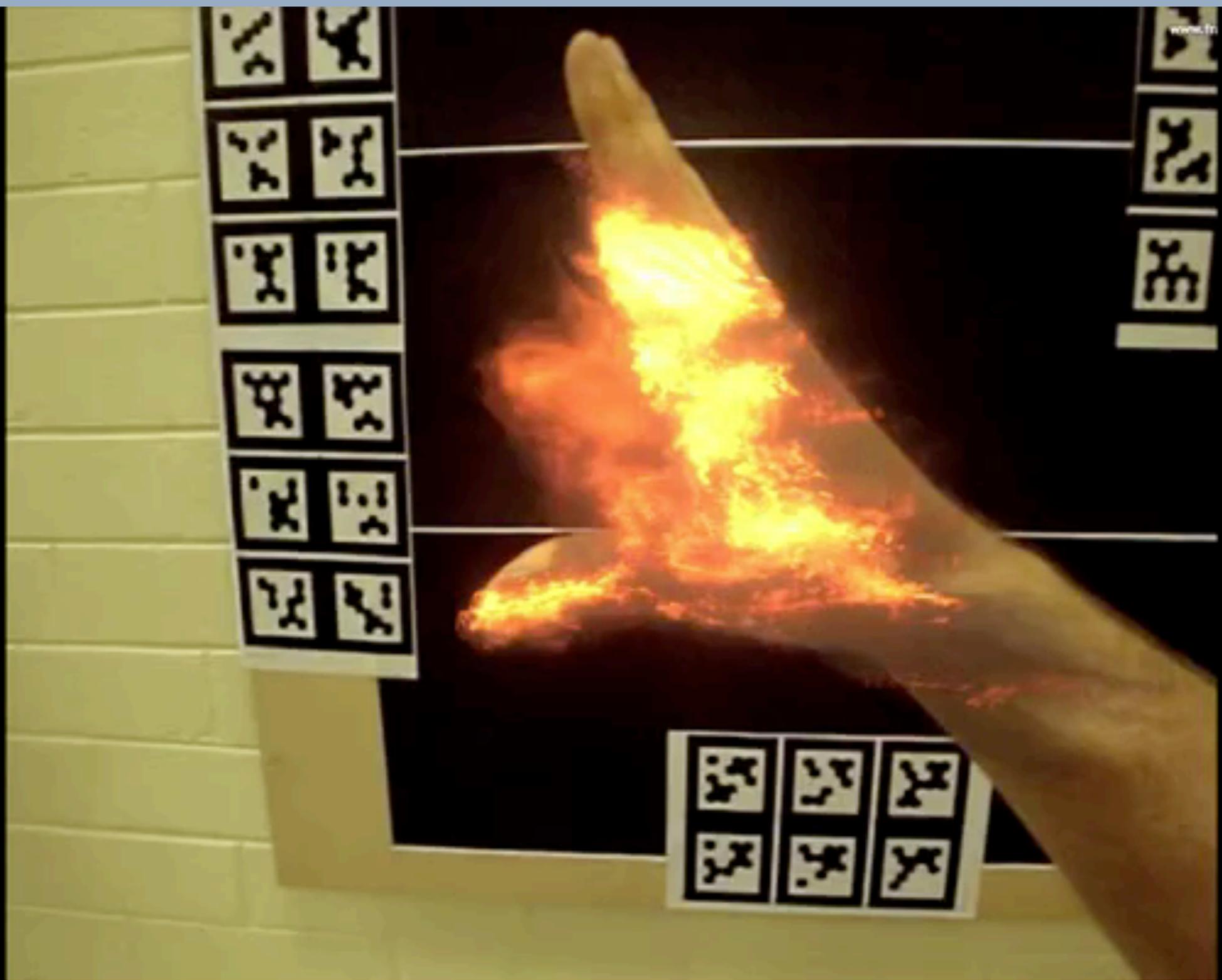
CHRISTIAN SANDOR  
CHRISTIAN@SANDOR.COM



# BURNAR: FEEL THE HEAT



MATT SWOBODA, THANH NGUYEN, ULRICH ECK, GERHARD REITMAYR, STEFAN HAUSWIESNER, RENE RANFTL, AND CHRISTIAN SANDOR. DEMO AT *IEEE INTERNATIONAL SYMPOSIUM ON MIXED AND AUGMENTED REALITY*, BASEL, SWITZERLAND, OCTOBER 2011. **BEST DEMO AWARD**



# Computer Vision

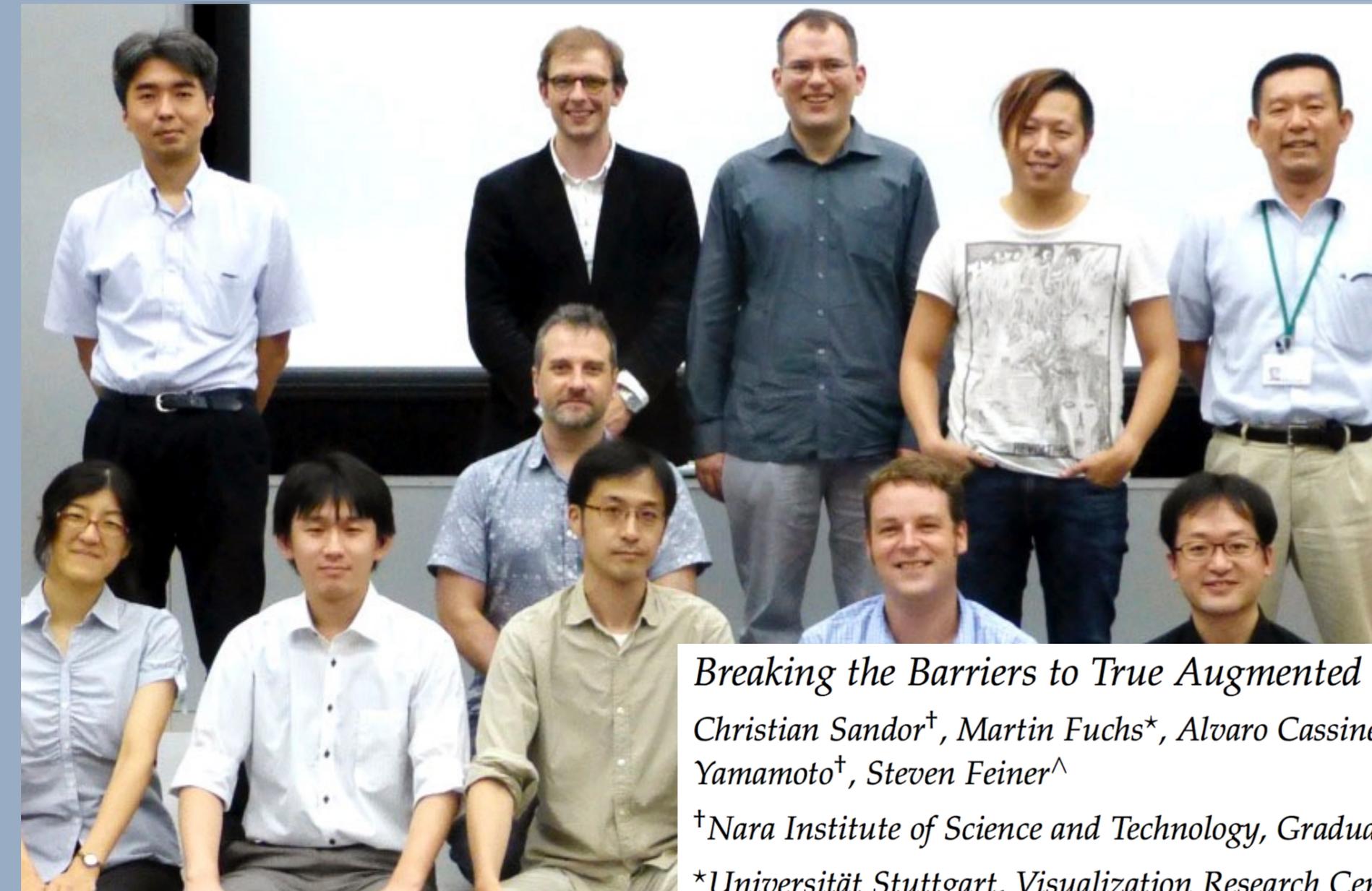
# Computer Graphics

# BURNAR: INVOLUNTARY HEAT SENSATIONS IN AR



PETER WEIR, CHRISTIAN SANDOR, MATT SWOBODA, THANH NGUYEN, ULRICH ECK, GERHARD REITMAYR, AND ARINDAM DEY. *PROCEEDINGS OF THE IEEE VIRTUAL REALITY CONFERENCE*, PAGES 43–46, ORLANDO, FL, USA, MARCH 2013.

# WORKSHOP AT NAIIST, AUGUST 2014



## *Breaking the Barriers to True Augmented Reality*

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*<sup>°</sup>University of Southern California, Department of Computer Science, USA*

*<sup>×</sup>University of Washington, Department of Computer Science and Engineering, USA*

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*December 17, 2015*

*ARXIV E-PRINTS, ARXIV:1512.05471 [CS.HC], 13 PAGES*

*HTTP://ARXIV.ORG/ABS/1512.05471*

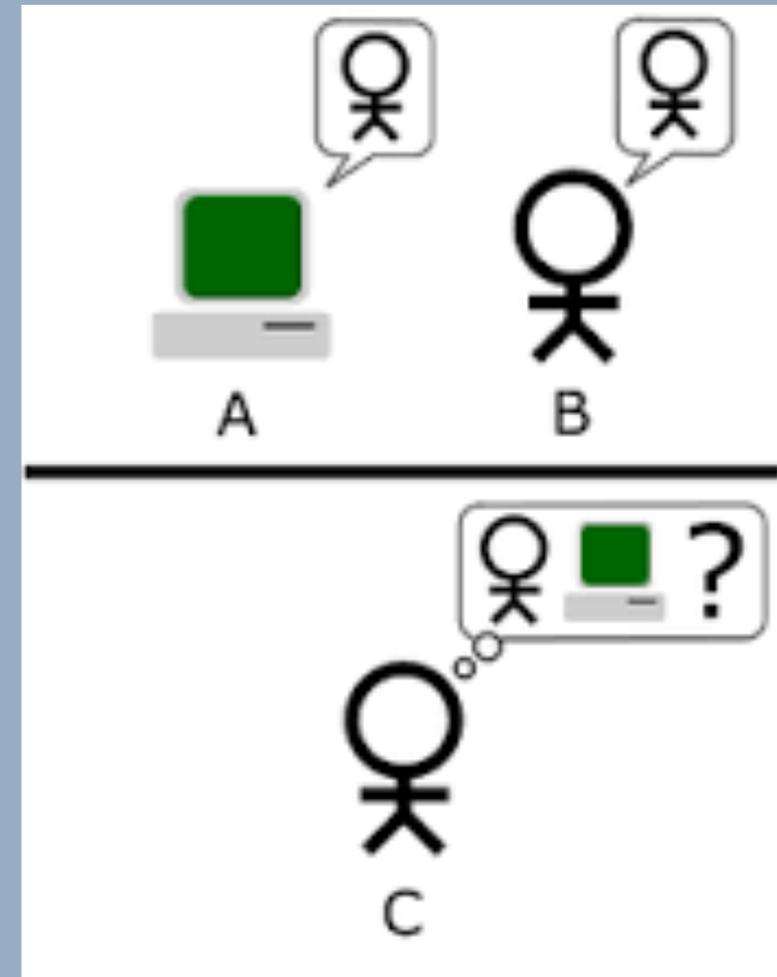
# TRUE AR: WHAT?

## DEFINITION:

1. UNDETECTABLE MODIFICATION OF USER'S PERCEPTION
2. GOAL: SEAMLESS BLEND OF REAL AND VIRTUAL WORLD

INSPIRED BY ALAN TURING'S **IMITATION GAME**

PURPOSE: TEST QUALITY OF AI



[HTTPS://EN.WIKIPEDIA.ORG/WIKI/TURING\\_TEST](https://en.wikipedia.org/wiki/Turing_Test)

ALAN TURING. COMPUTING MACHINERY AND INTELLIGENCE. *MIND*, 59 (236): 433–460, OCTOBER 1950.

# RELATION TO OTHER TURING TESTS

*DIFFICULTY*



**AUGMENTED REALITY**

**VIRTUAL REALITY**

**VISUAL COMPUTING:** QI SHAN, RILEY ADAMS, BRIAN CURLESS, YASUTAKA FURUKAWA, STEVEN M. SEITZ:  
THE VISUAL TURING TEST FOR SCENE RECONSTRUCTION. *3DV 2013*: 25-32

**COMPUTER GRAPHICS:** MICHAEL D. MCGUIGAN.  
GRAPHICS TURING TEST. *ARXIV E-PRINTS*, ARXIV:CS/  
0603132V1, 2006

# TRUE AR: WHY?

TRAINING: SPORTS & SKILLS

AMUSEMENT: INTERACTIVE STORIES

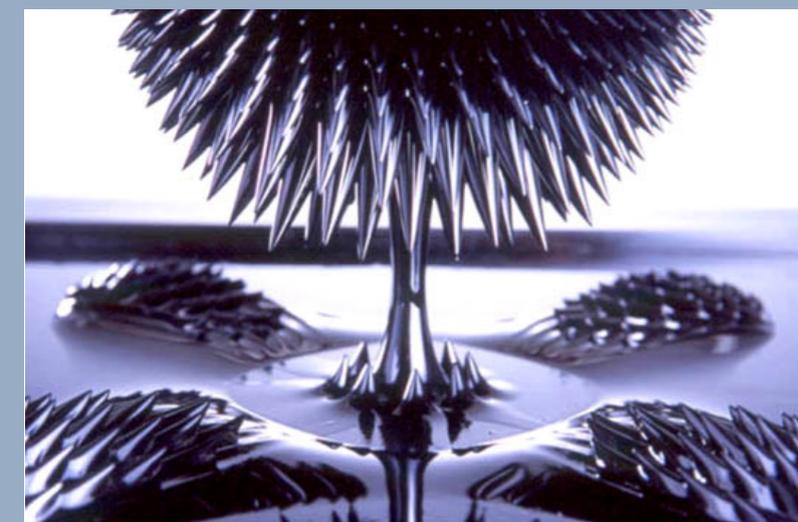
SCIENCE: PSYCHOLOGY & NEUROSCIENCE

LAW: FORENSICS & LOGISTICS OF CRIME SCENE

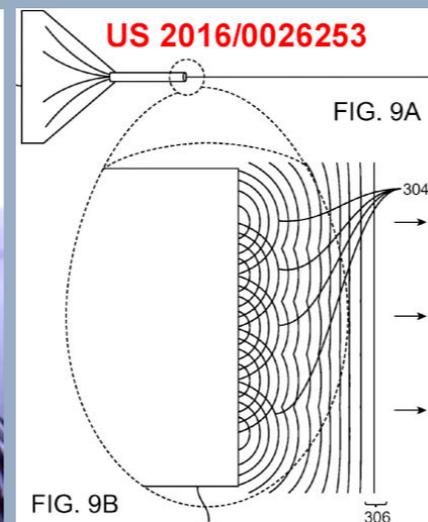


STAR TREK HOLODECK. [HTTPS://EN.WIKIPEDIA.ORG/WIKI/HOLODECK](https://en.wikipedia.org/wiki/Holodeck)

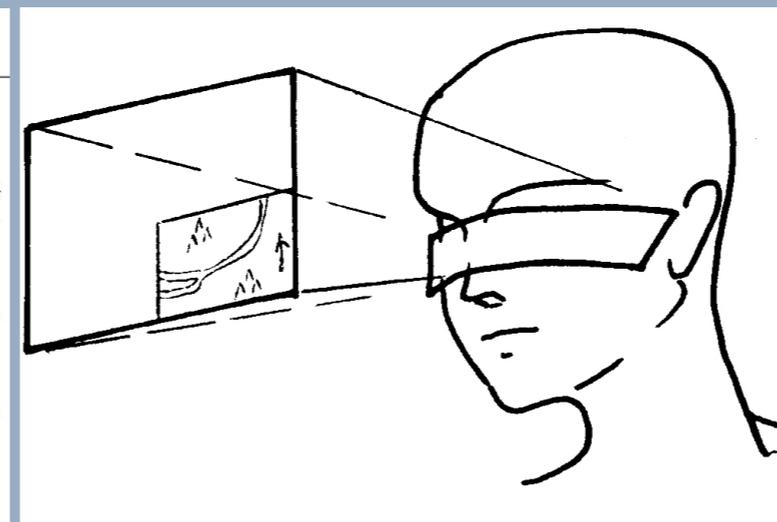
# TRUE AR: HOW?



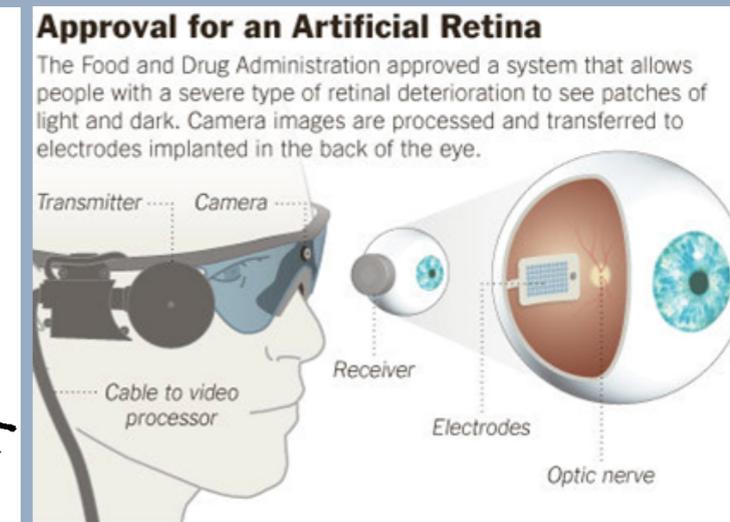
CONTROLLED  
MATTER



SURROUND  
AR



PERSONALIZED AR

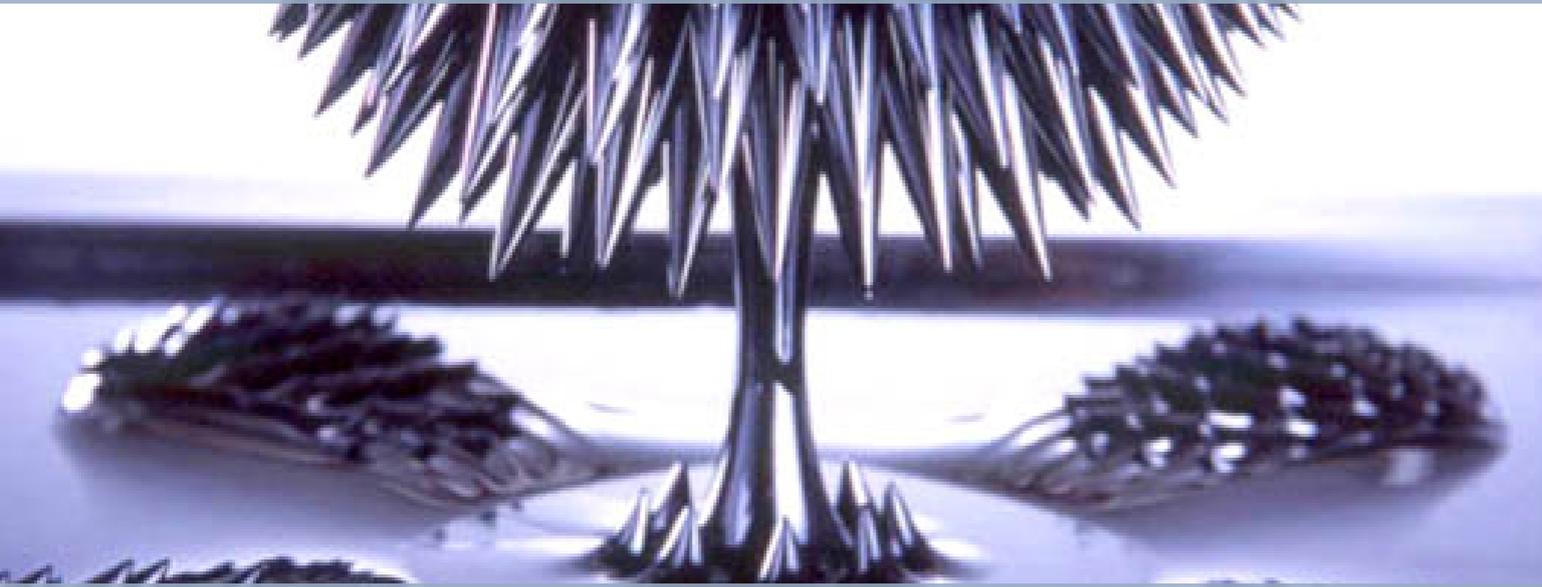


IMPLANTED AR

MANIPULATING  
ATOMS

MANIPULATING  
PERCEPTION

# CONTROLLED MATTER



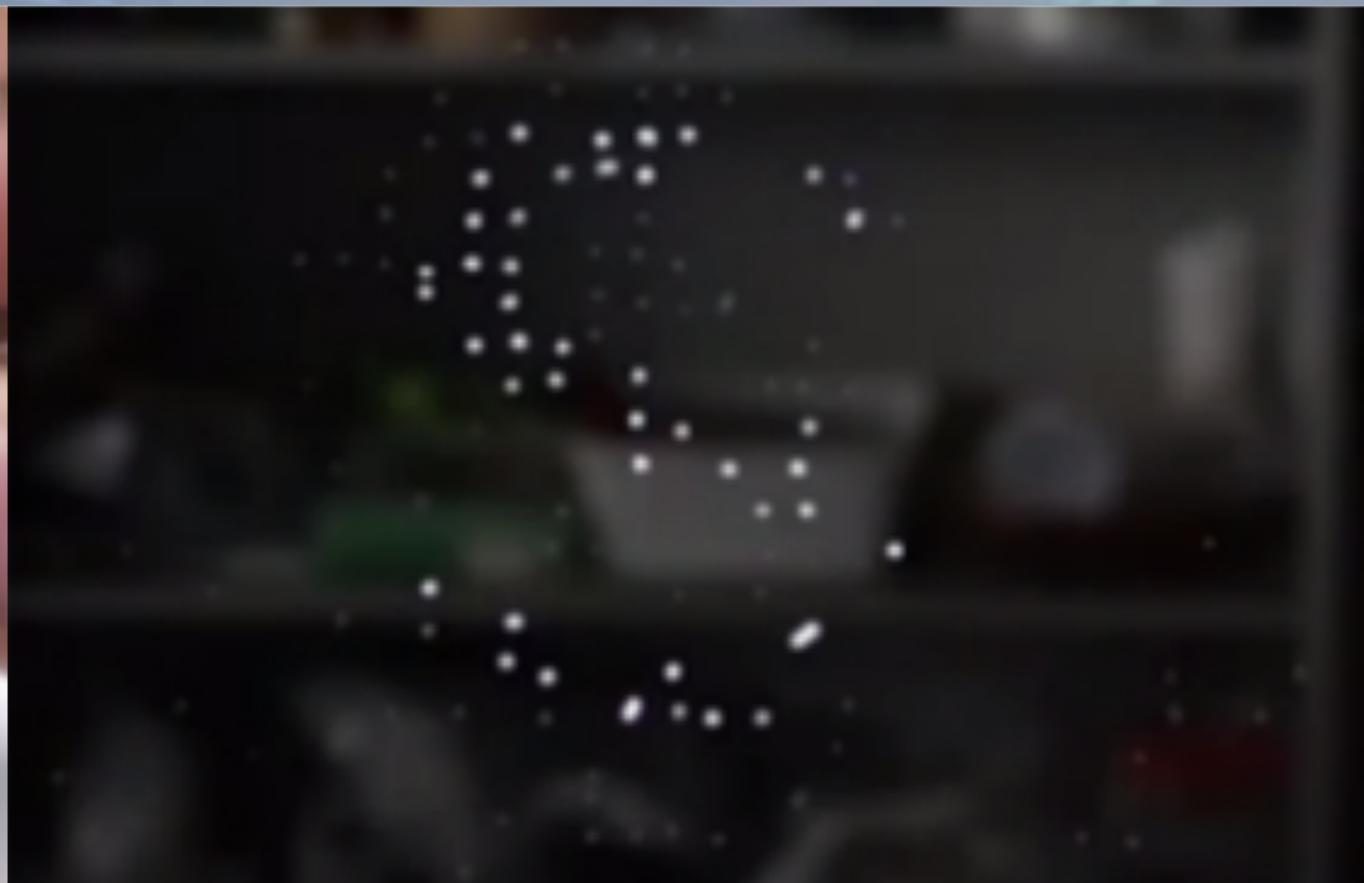
SACHIKO KODAMA. PROTRUDE, FLOW. ACM SIGGRAPH 2001 ART GALLERY.



[HTTP://TANGIBLE.MEDIA.MIT.EDU/PROJECT/INFORM](http://tangible.media.mit.edu/project/inform)



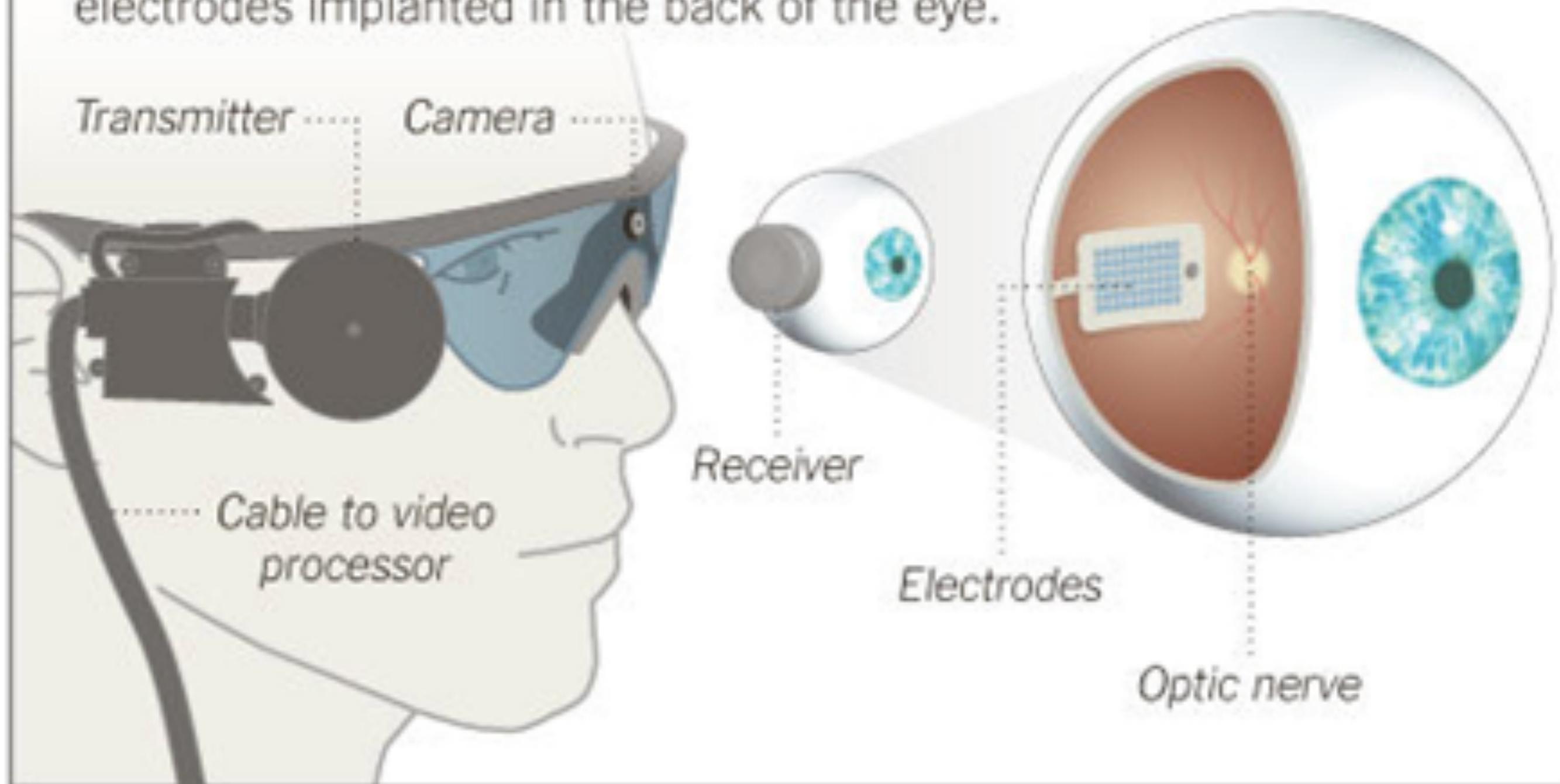
[HTTP://PIXIEDUSTTECH.COM](http://pixiedusttech.com)



# IMPLANTED AR

## Approval for an Artificial Retina

The Food and Drug Administration approved a system that allows people with a severe type of retinal deterioration to see patches of light and dark. Camera images are processed and transferred to electrodes implanted in the back of the eye.



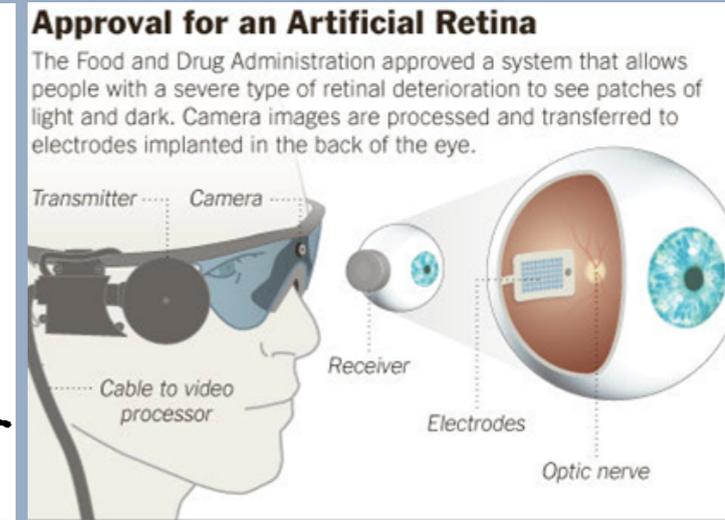
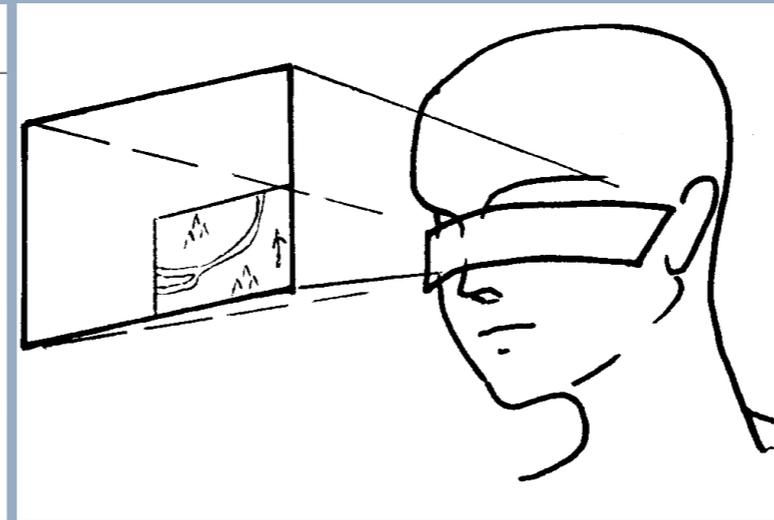
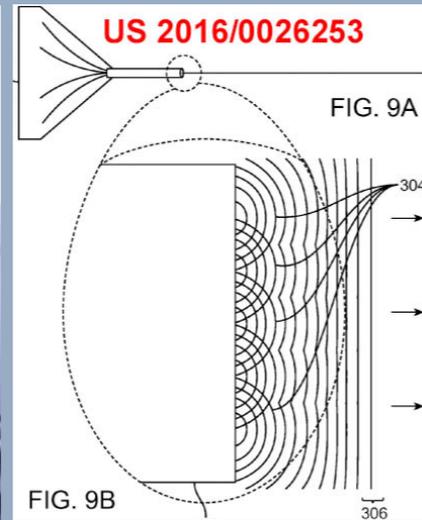
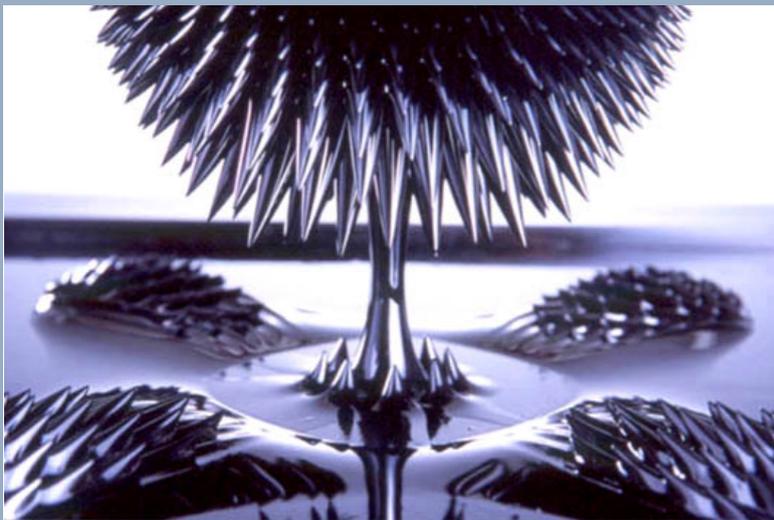
# SURROUND VS. PERSONALIZED AR

LIGHT FIELD DISPLAYS:

FULL

PERCEIVABLE

SUBSET



CONTROLLED  
MATTER

SURROUND  
AR

PERSONALIZED AR

IMPLANTED AR

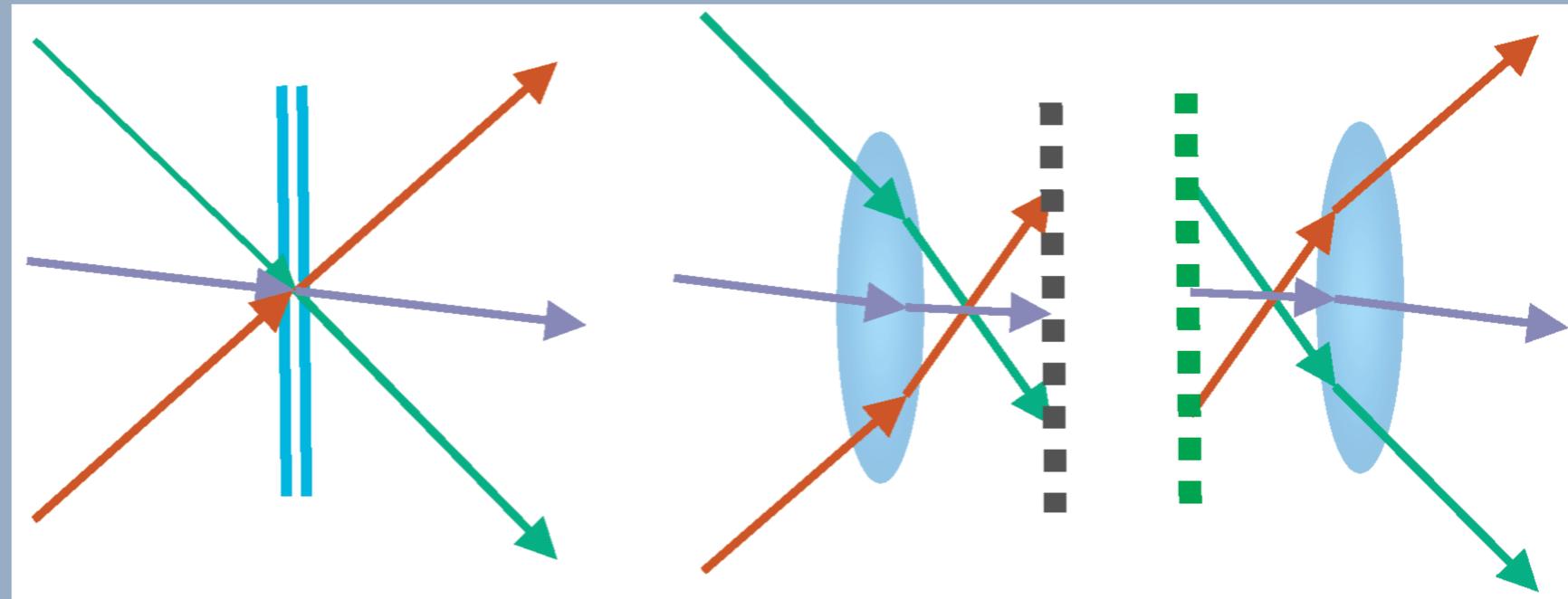


*MANIPULATING  
ATOMS*

*MANIPULATING  
PERCEPTION*

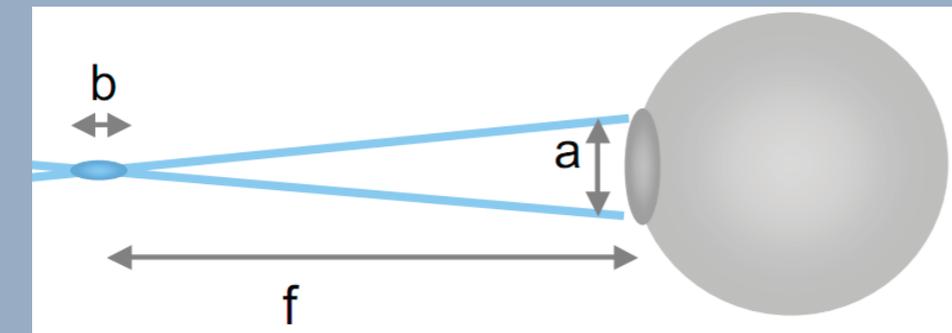
# LIGHT FIELD DISPLAYS

**VISION:**  
DISPLAY AS WINDOW

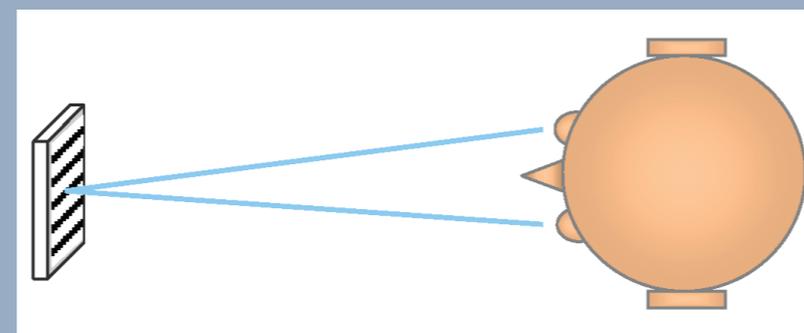


SENSOR ARRAY    DISPLAY ARRAY

**GOAL:** NATURAL HUMAN VISUAL PERCEPTION

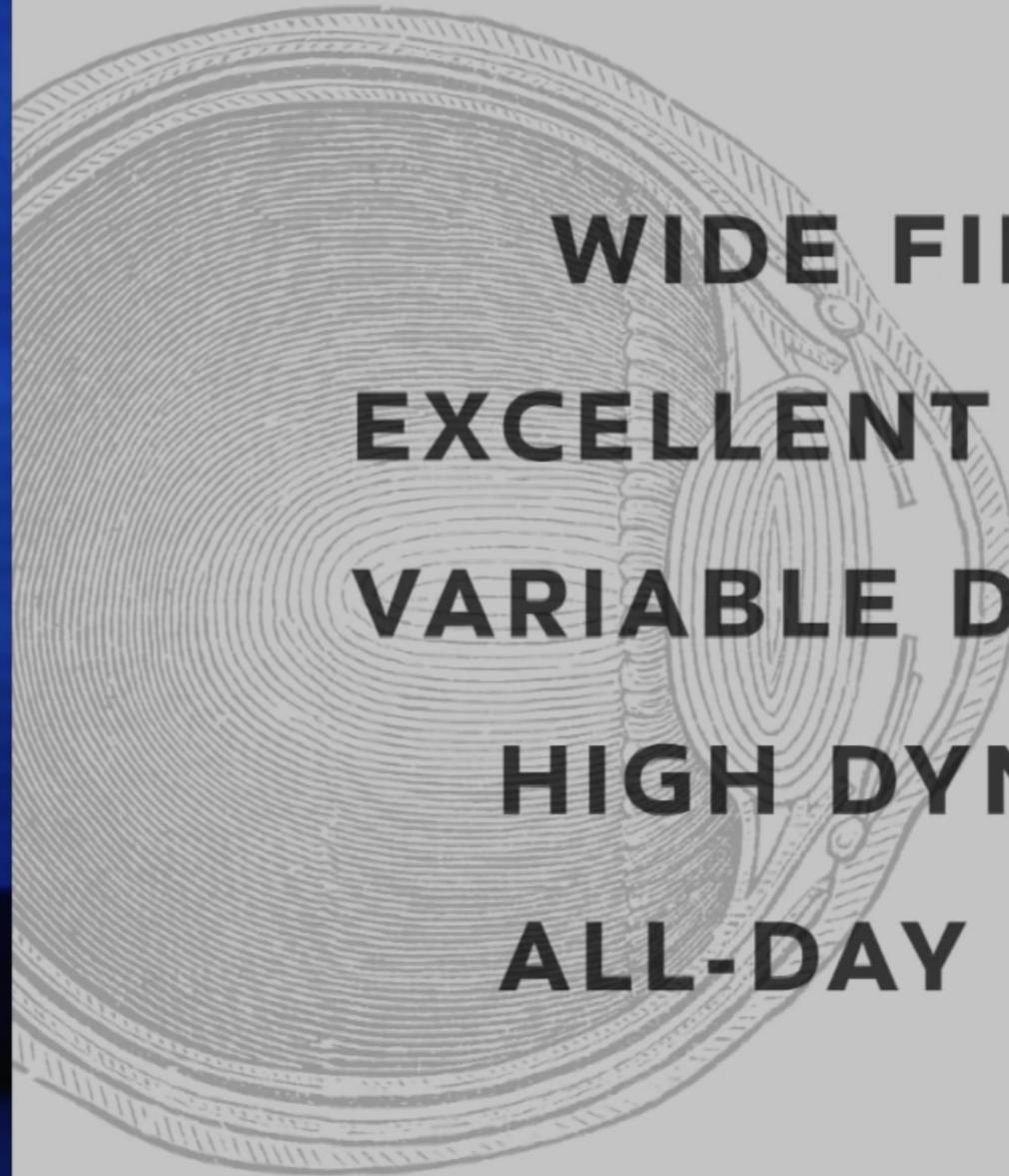
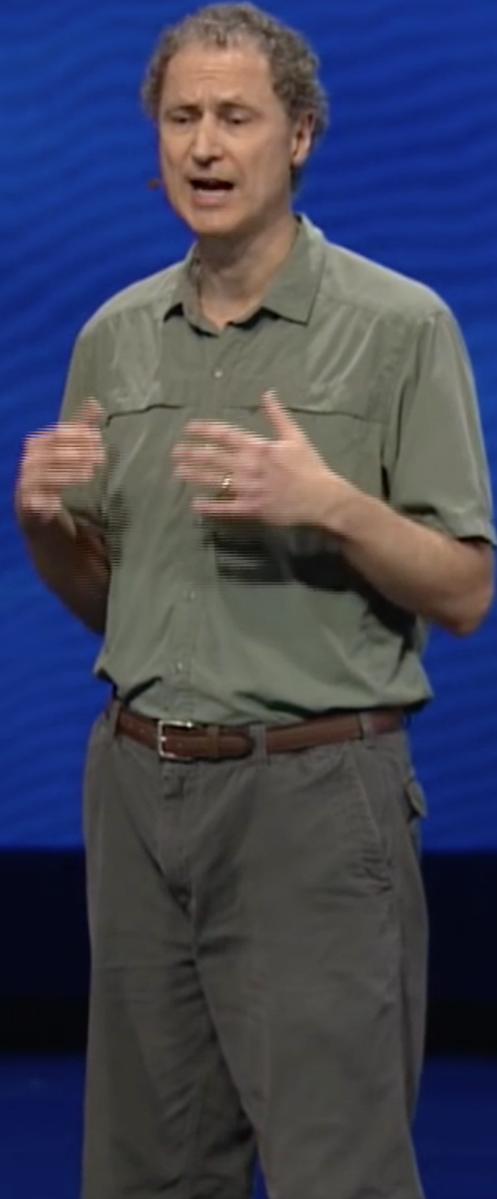


ACCOMMODATION



VERGENCE

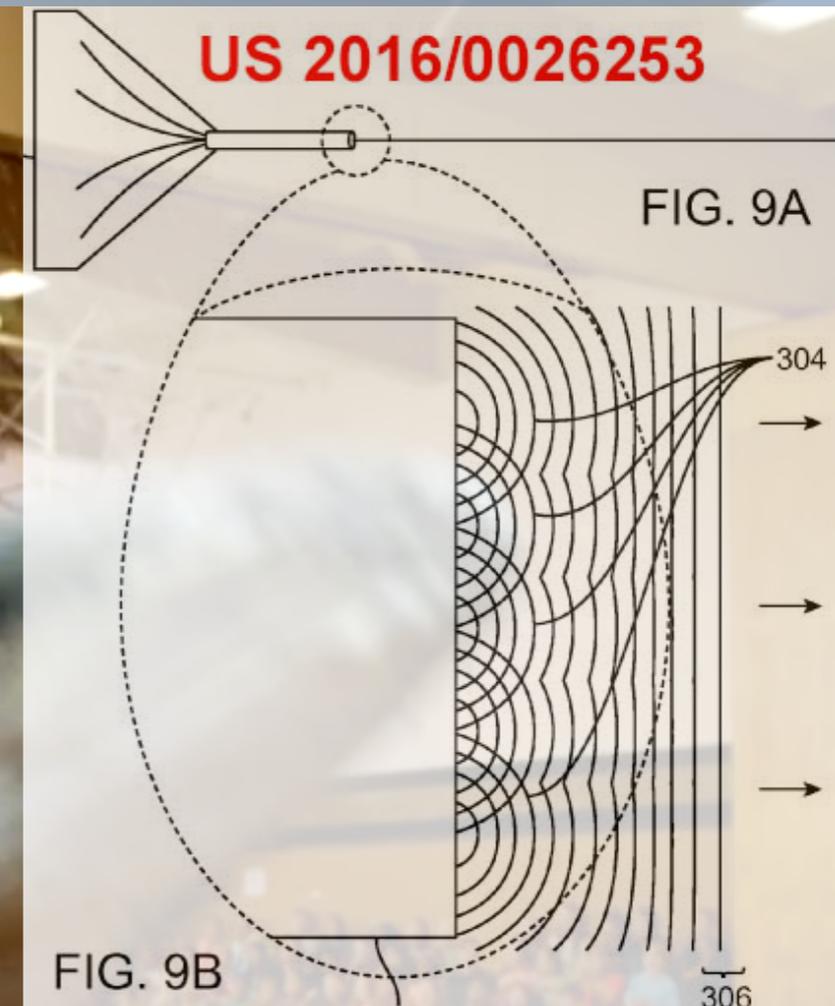
# FUTURE OCULUS DISPLAYS



**WIDE FIELD OF VIEW**  
**EXCELLENT IMAGE QUALITY**  
**VARIABLE DEPTH OF FOCUS**  
**HIGH DYNAMIC RANGE**  
**ALL-DAY ERGONOMICS**

MICHAEL ABRASH. *OCULUS CONNECT 2 KEYNOTE*. OCTOBER 2015

# SURROUND AR: MAGIC LEAP

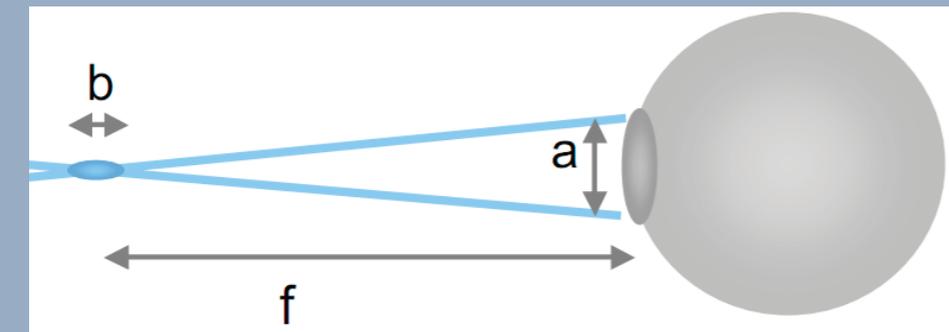


## Funding Rounds (3) - \$1.39B

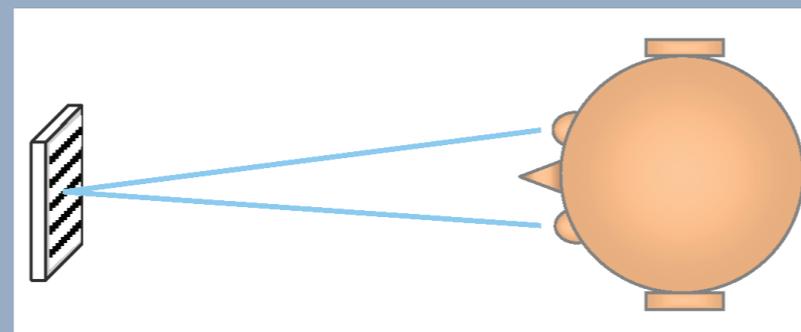
Date	Amount / Round	Valuation	Lead Investor	Investors
Feb, 2016	\$793.5M / <a href="#">Series C</a>	—	<a href="#">Alibaba</a>	<a href="#">9</a>
Oct, 2014	\$542M / <a href="#">Series B</a>	—	<a href="#">Google</a>	<a href="#">8</a>
Feb, 2014	\$50M / <a href="#">Series A</a>	—	—	<a href="#">0</a>

# PERSONALIZED AR: A SMARTER APPROACH

**KEY IDEA: MEASURE HUMAN VISUAL SYSTEM & DISPLAY SUBSET OF LIGHT FIELD**



ACCOMMODATION



VERGENCE

**BENEFIT: REDUCE REQUIRED DISPLAY PIXELS BY SEVERAL ORDERS OF MAGNITUDE**

**WILL BE ACHIEVED WELL BEFORE SURROUND AR!**

# DISPLAYS

REMOVE

CREATE

GEOMETRIC

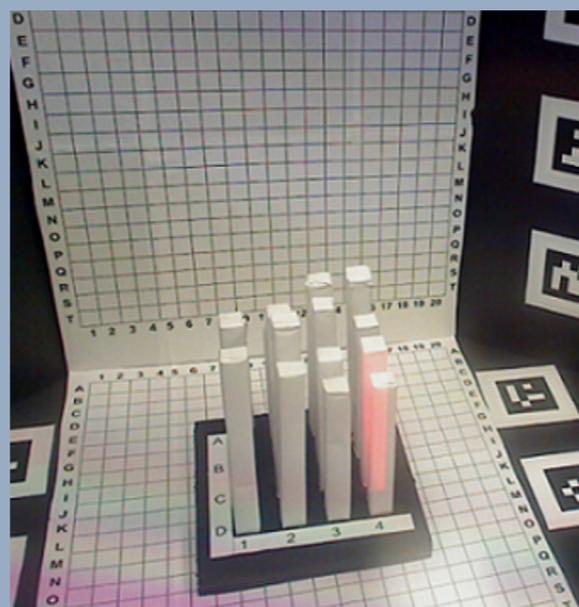
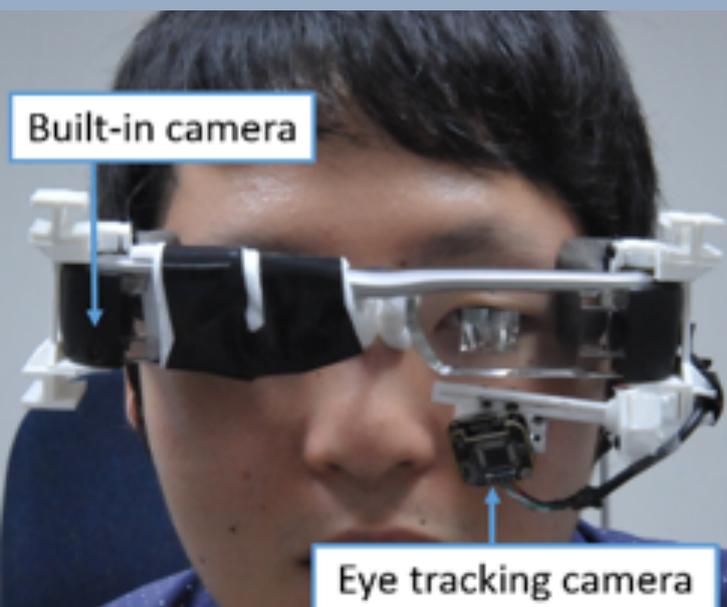
BLUR

CORRECT

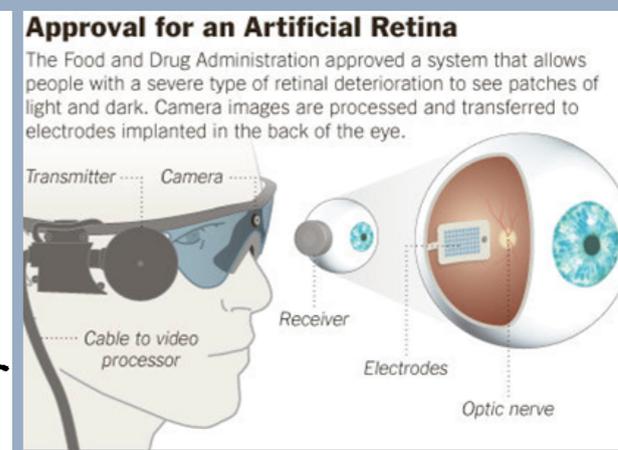
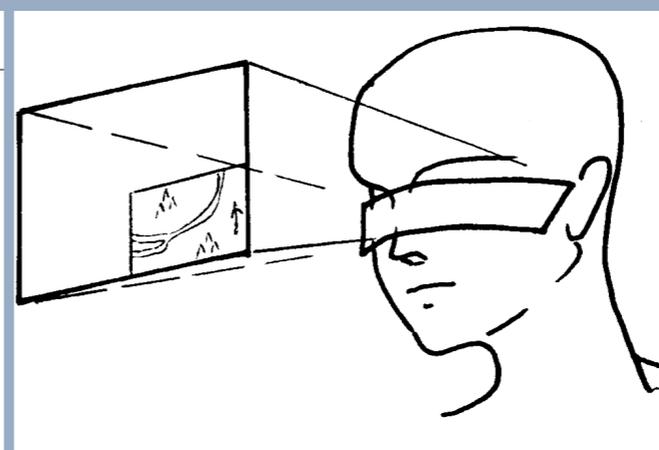
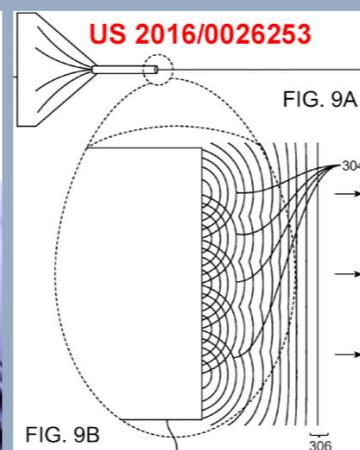
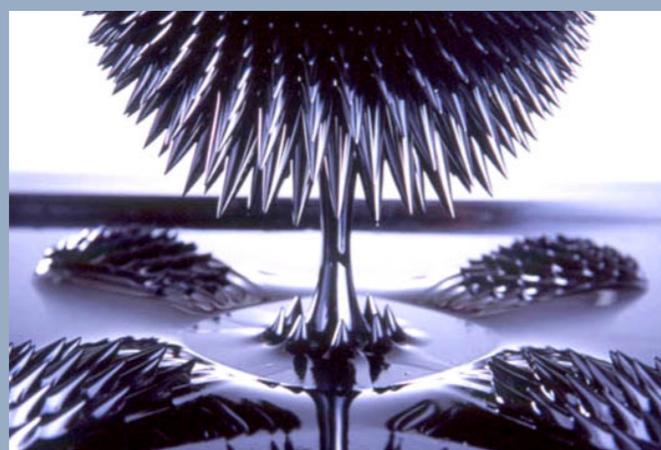
ALIGNMENT

ARTIFACTS

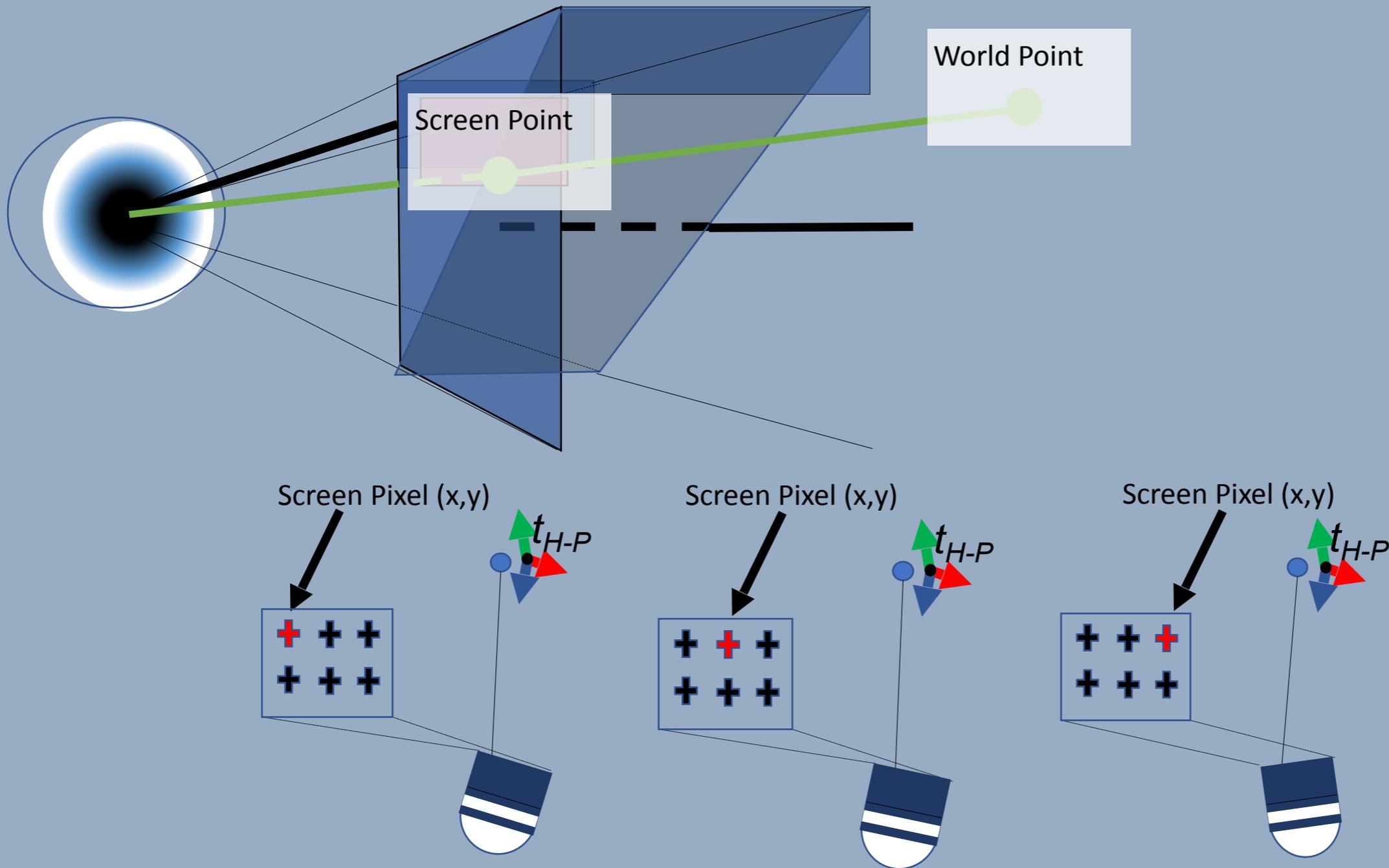
BLUR



# PHILOSOPHY: TRUE AUGMENTED REALITY

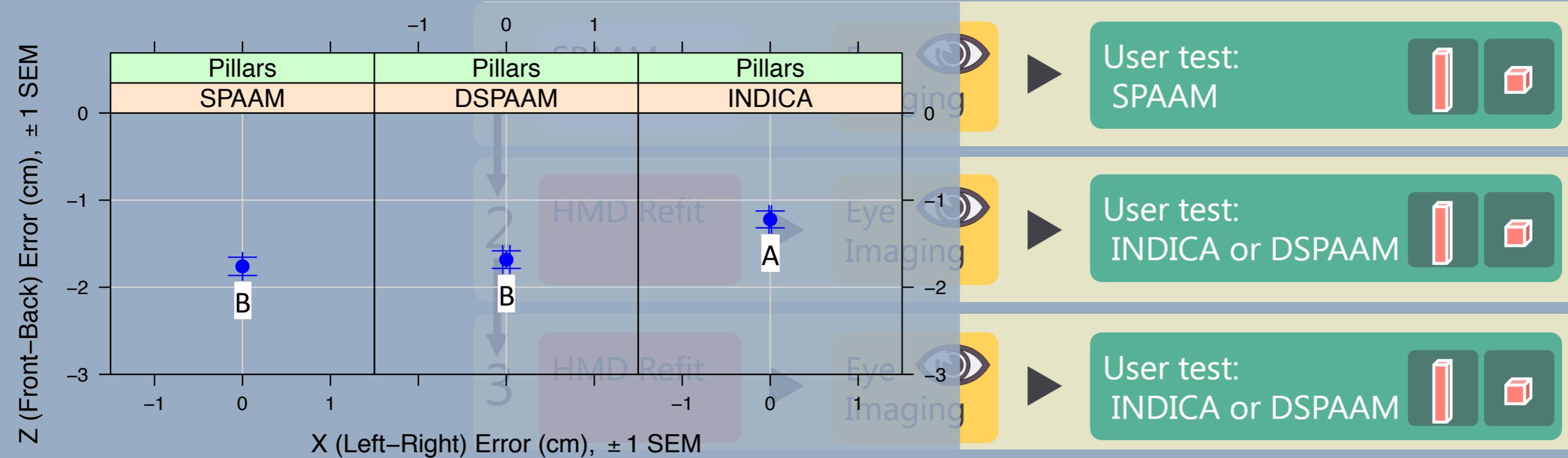
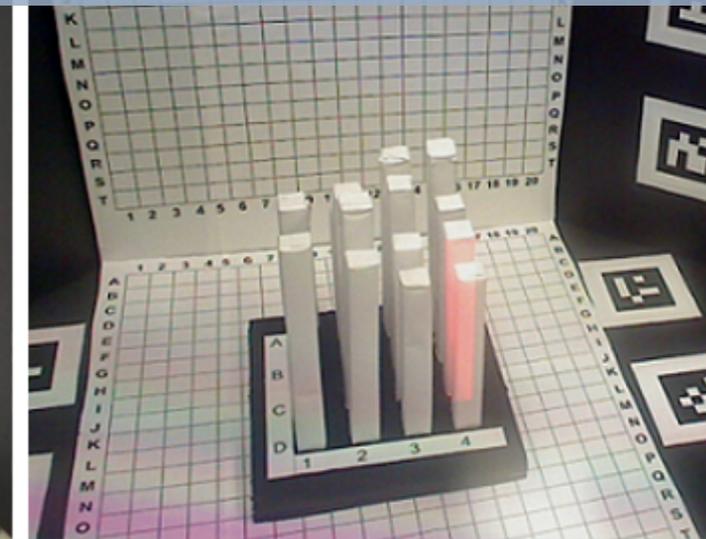


# GEOMETRIC ALIGNMENT: SPAAM



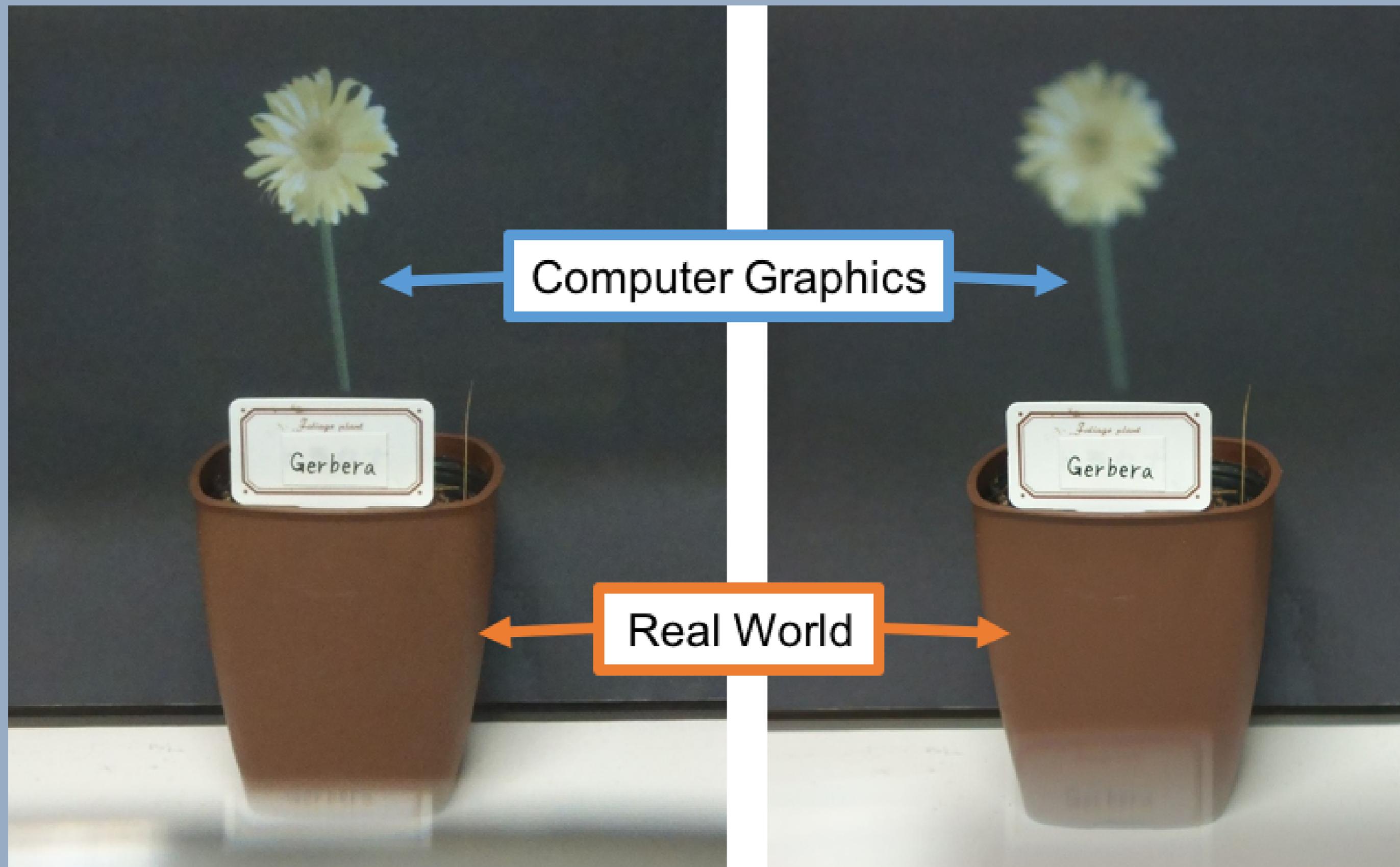
MIHRAN TUCERYAN, YAKUP GENÇ, AND NASSIR NAVAB. SINGLE-POINT ACTIVE ALIGNMENT METHOD (SPAAM) FOR OPTICAL SEE-THROUGH HMD CALIBRATION FOR AUGMENTED REALITY. *PRESENCE: TELEOPERATORS AND VIRTUAL ENVIRONMENTS*, 11(3):259-276, JUNE 2002.

# OUR METHOD: ONLY SPAAM ONCE



KENNETH MOSER, YUTA ITOH, KOHEI OSHIMA, EDWARD SWAN, GUDRUN KLINKER, AND CHRISTIAN SANDOR. SUBJECTIVE EVALUATION OF A SEMI-AUTOMATIC OPTICAL SEE-THROUGH HEAD-MOUNTED DISPLAY CALIBRATION TECHNIQUE. *IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS*, 21(4):491–500, MARCH 2015.

# BLUR ARTIFACTS

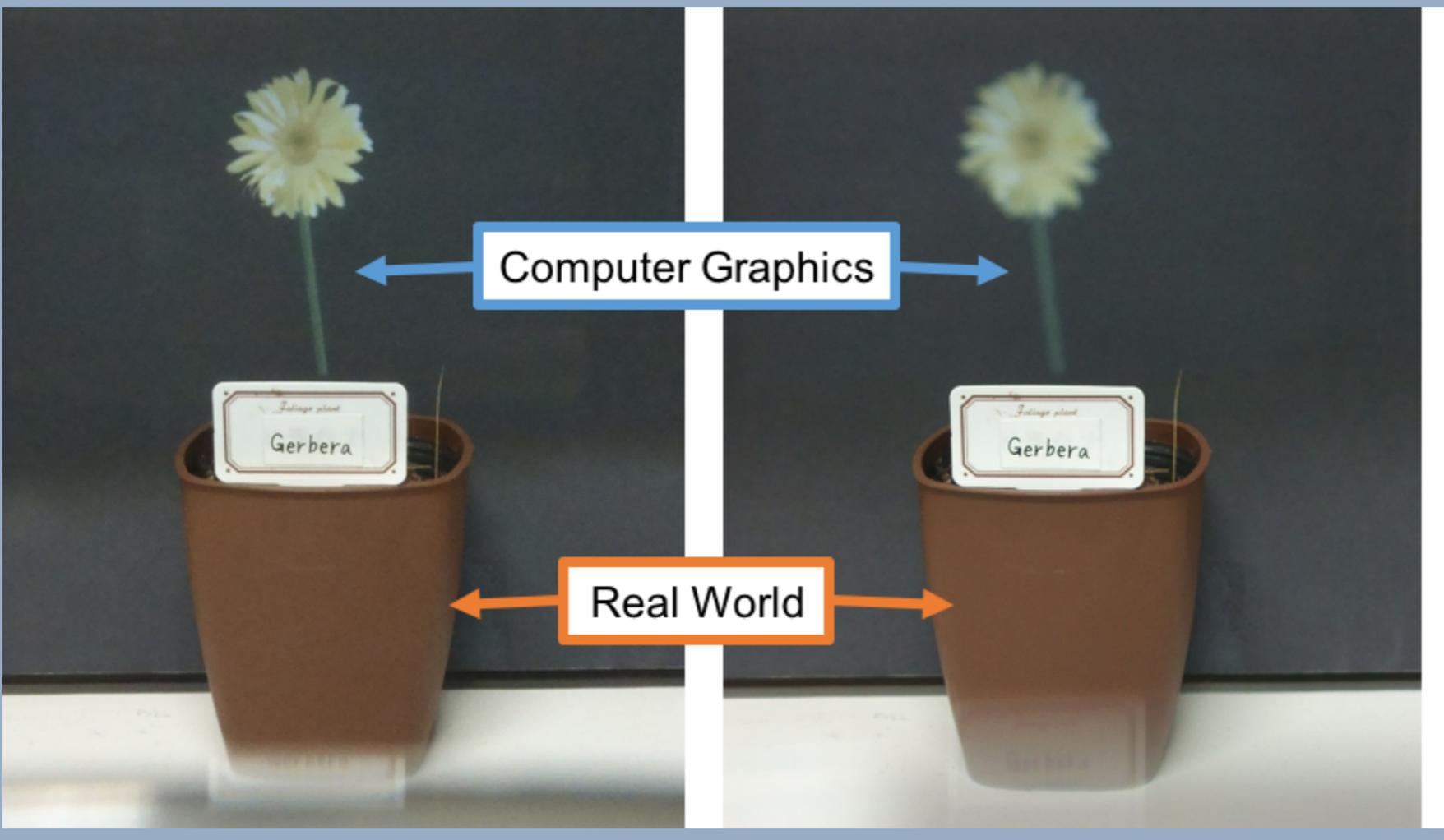
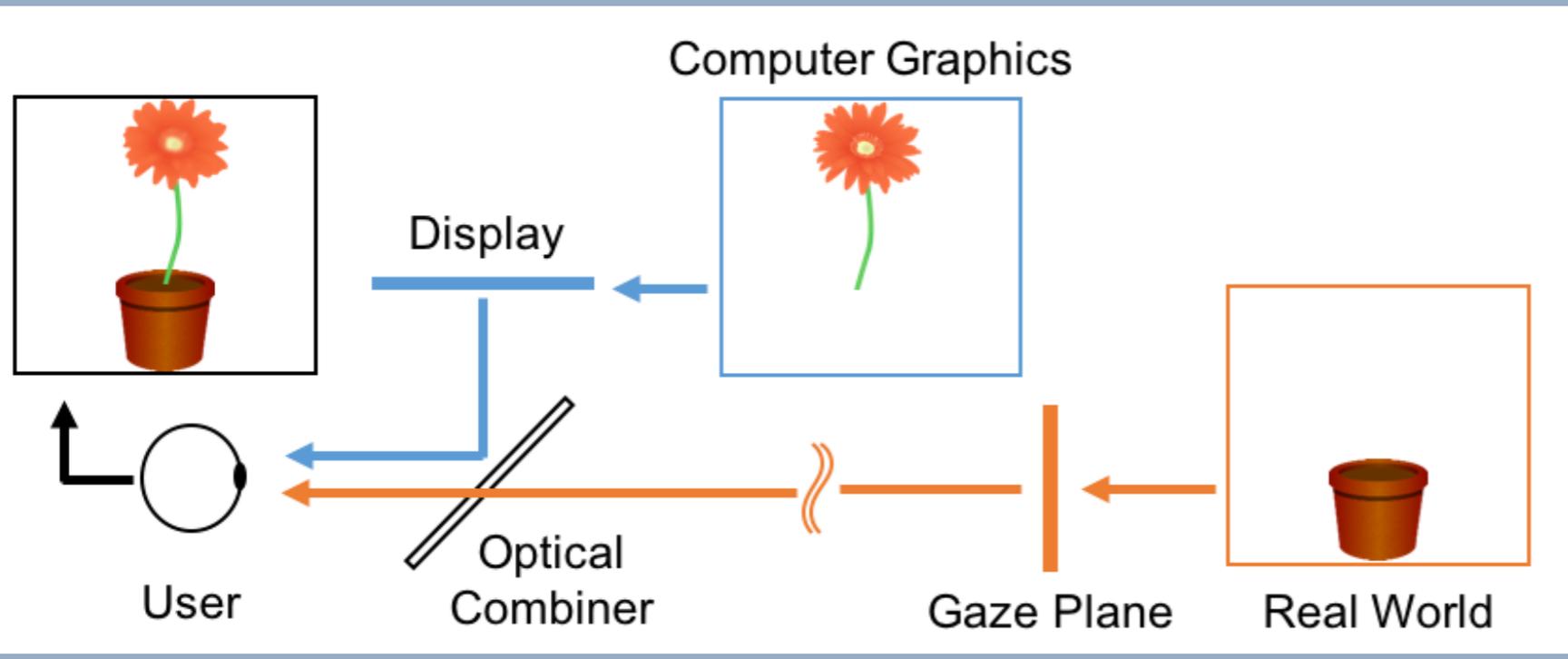
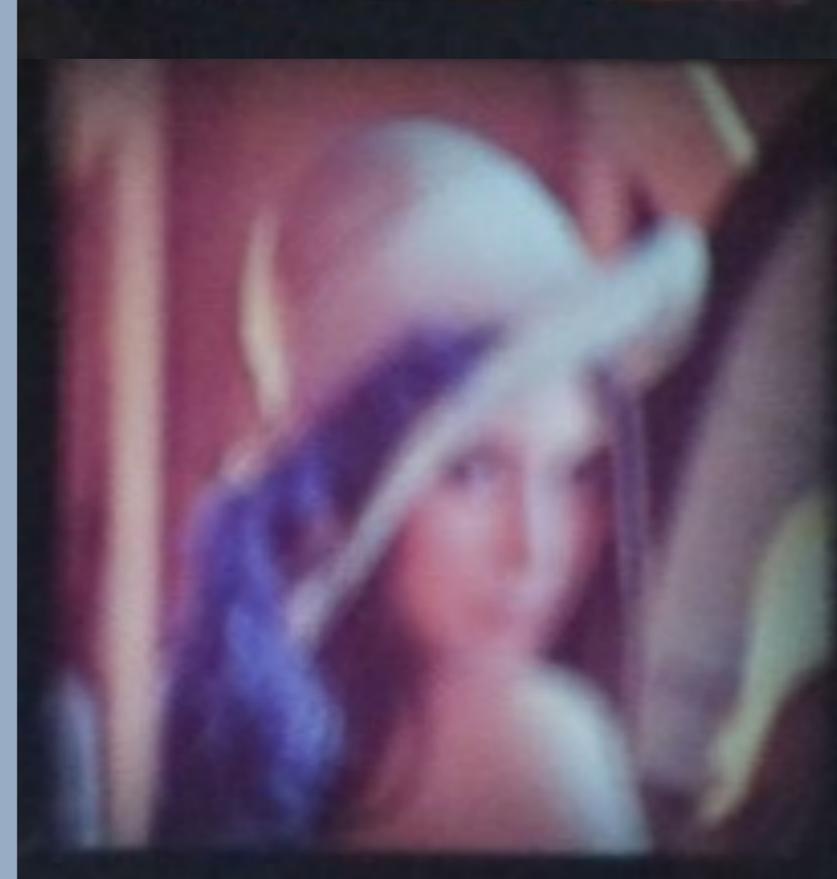
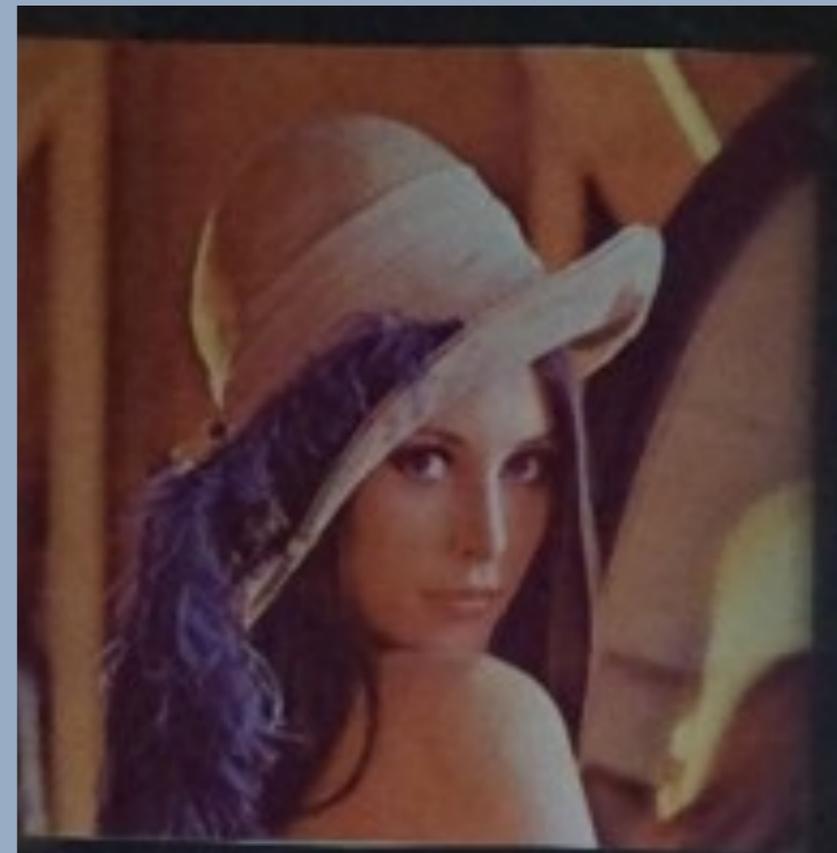


DESIRED

MOST DISPLAYS

# BLUR ARTIFACTS

REAL PHOTO



DESIRED

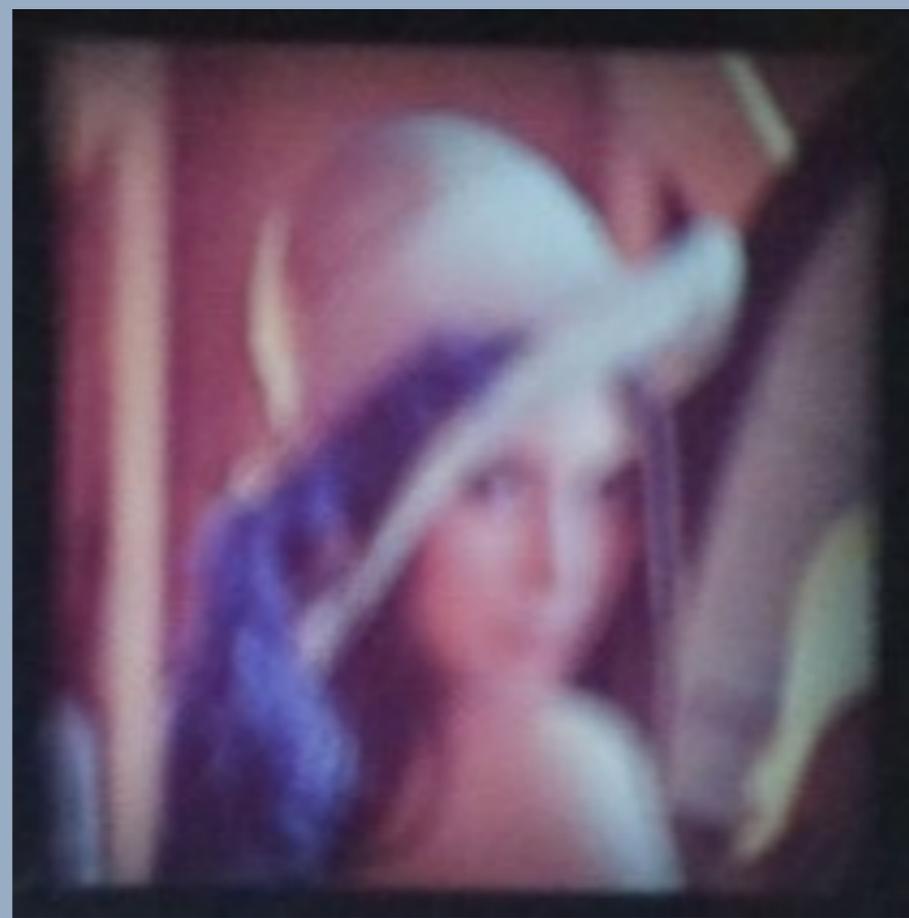
MOST DISPLAYS

“MATCHING” IMAGE

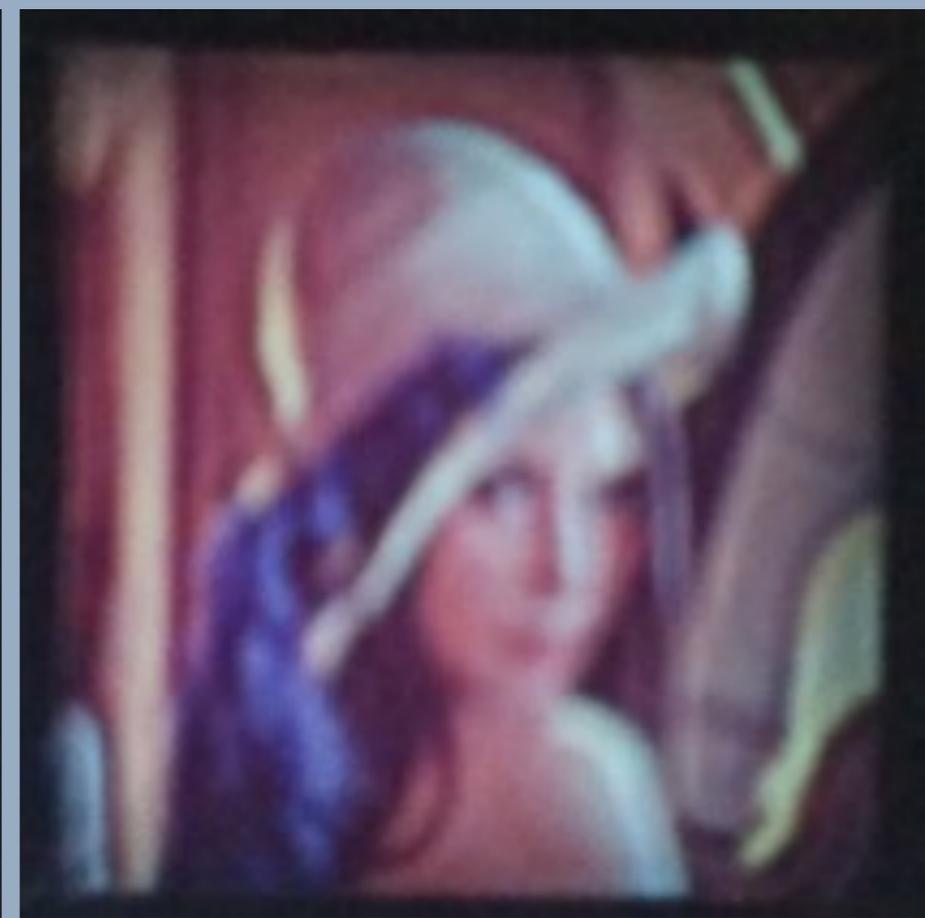
# OUR METHOD: SHARPVIEW



REAL PHOTO



“MATCHING” IMAGE



SHARPVIEW

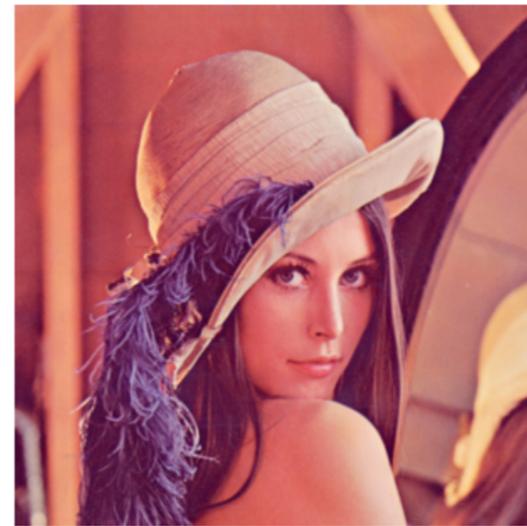
KOHEI OSHIMA, KENNETH R MOSER, DAMIEN CONSTANTINE ROMPAPAS, J EDWARD SWAN II, SEI IKEDA, GOSHIRO YAMAMOTO, TAKAFUMI TAKETOMI, CHRISTIAN SANDOR, AND HIROKAZU KATO. IMPROVED CLARITY OF DEFOCUSSED CONTENT ON OPTICAL SEE-THROUGH HEAD-MOUNTED DISPLAYS. IN *IEEE SYMPOSIUM ON 3D USER INTERFACES*, PAGES 173–181, GREENVILLE, SOUTH CAROLINA, USA, MARCH 2016.

# BASIC IDEA: PRE-SHARPENING

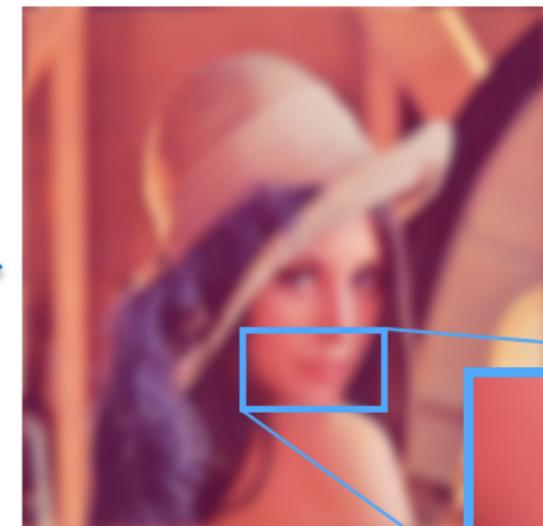
Focus blur is represented  
by convolution

$$o * p = b$$

※  $p$  : Point Spread Function (PSF)



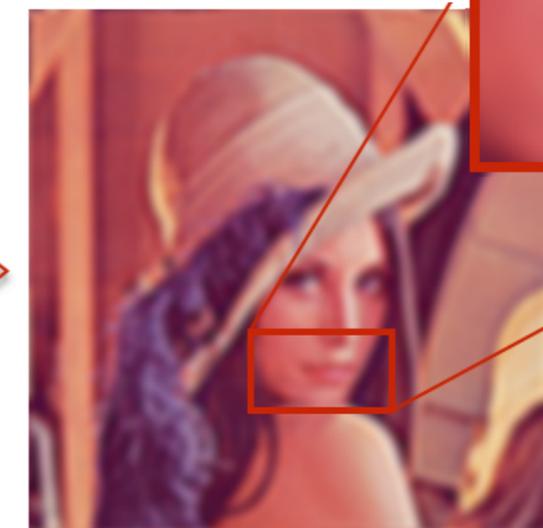
Original(o)



Blurred(b)



Sharpened(s)

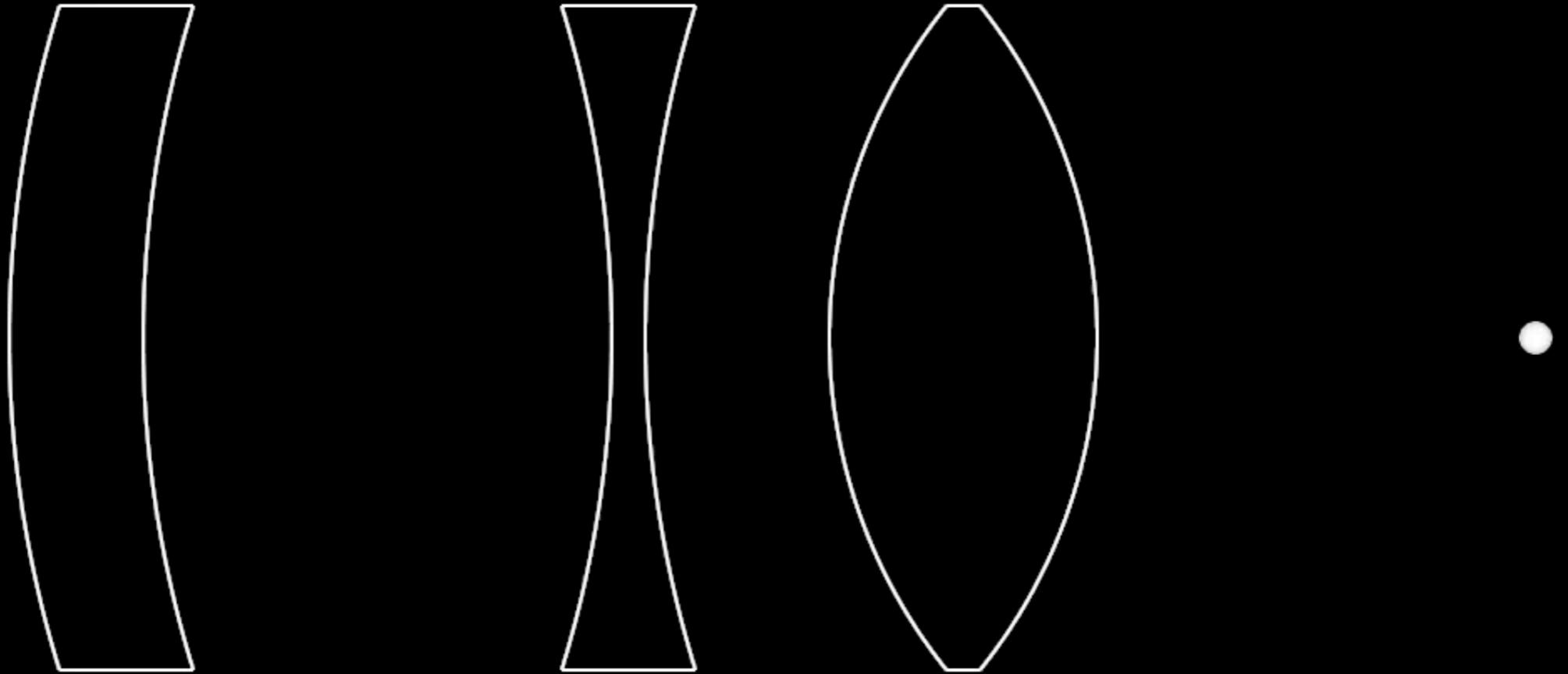


Restored(r)

Over sharpened image is improved  
by focus blur

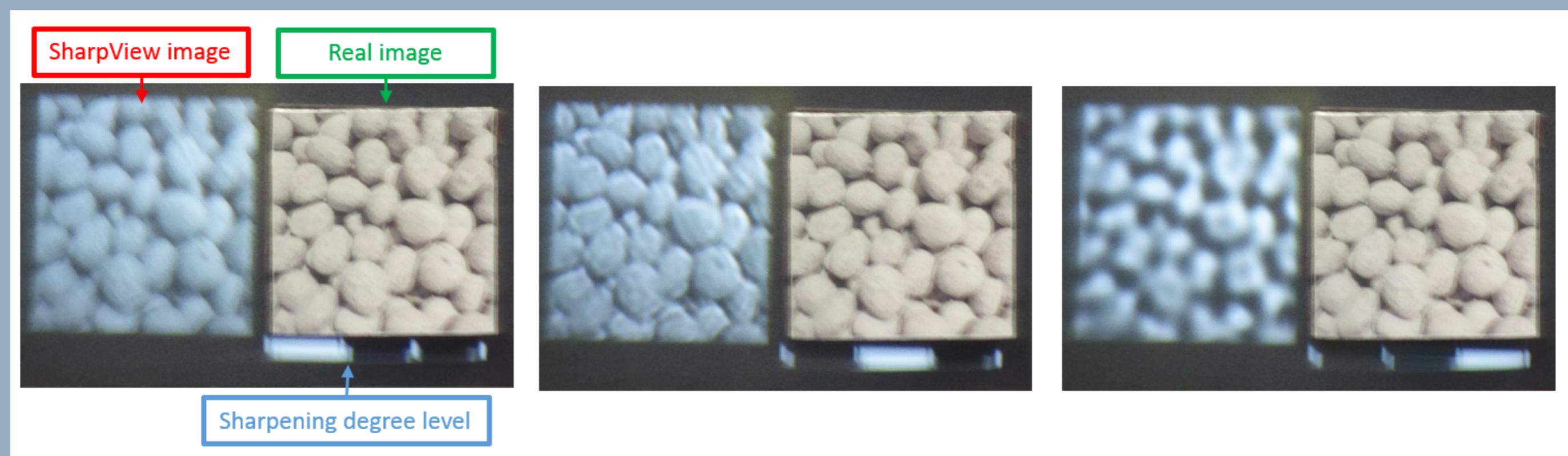
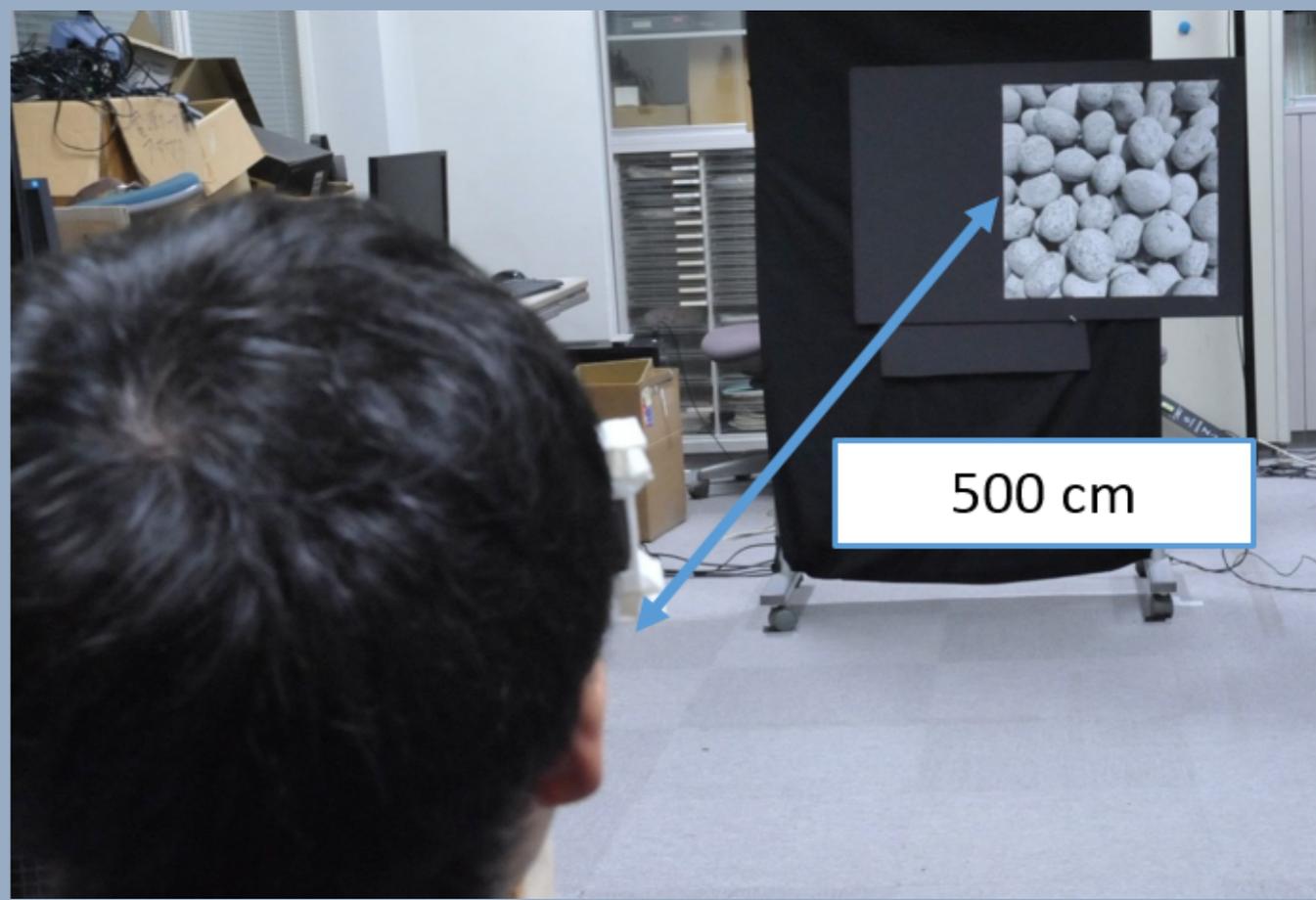
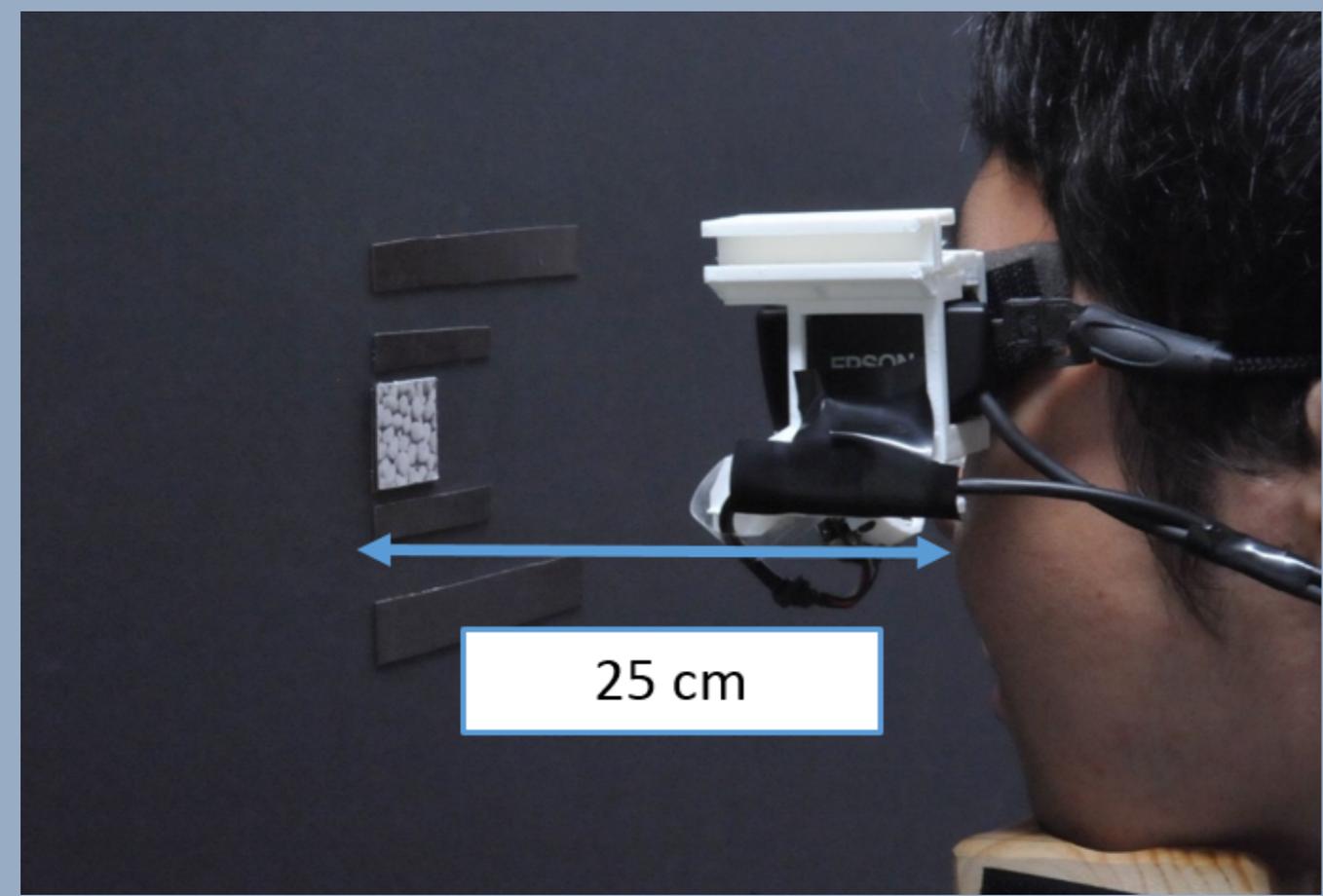
$$s * p = r$$

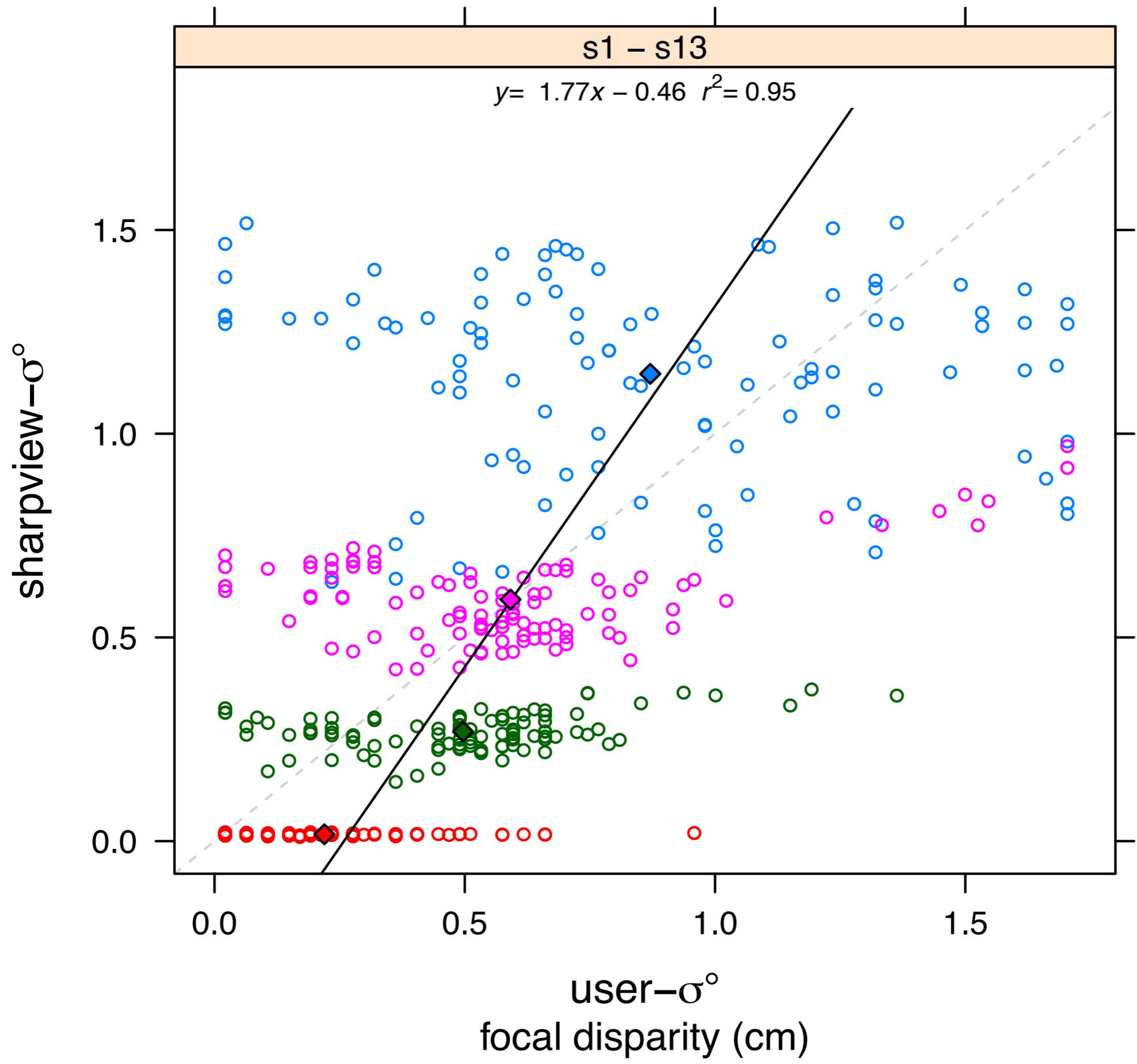
# VISUALIZATION OF PSF





# OUR EXPERIMENT





675



650



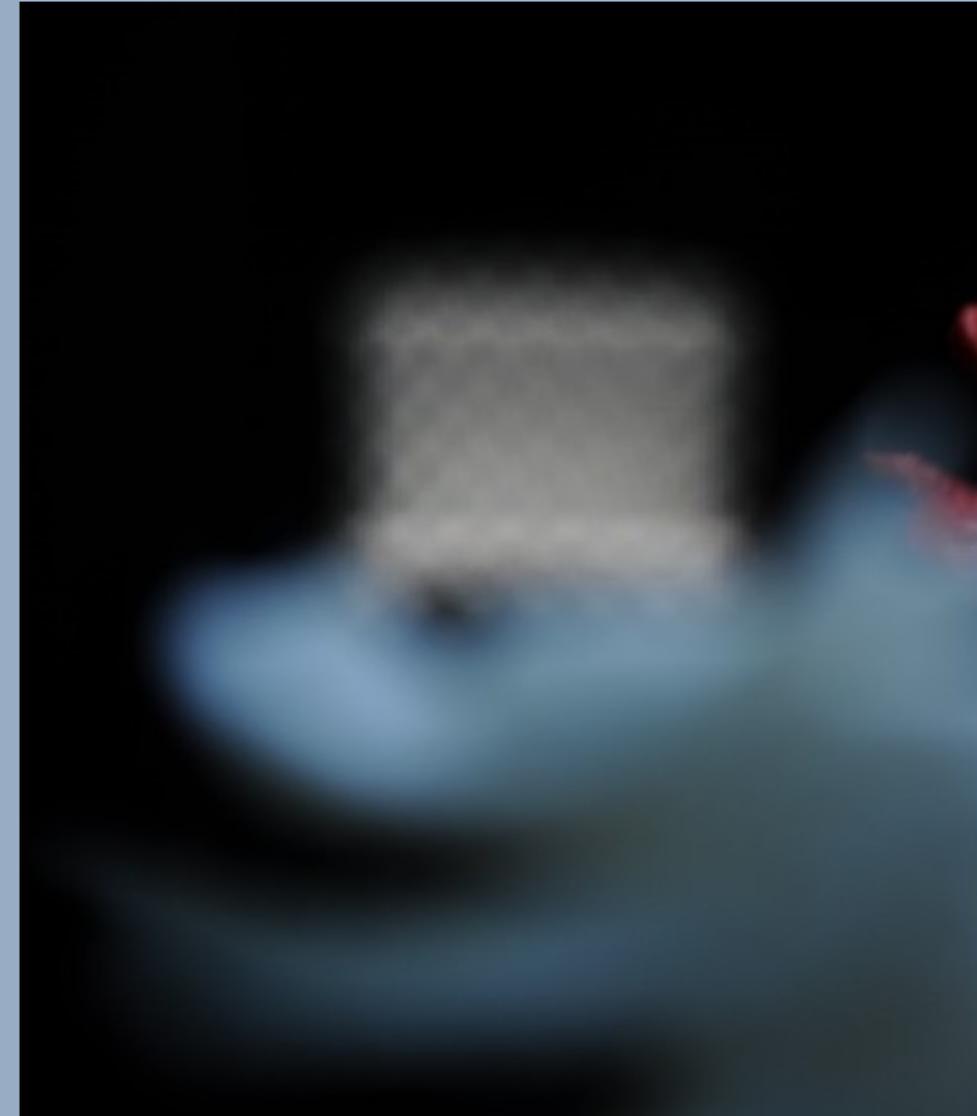
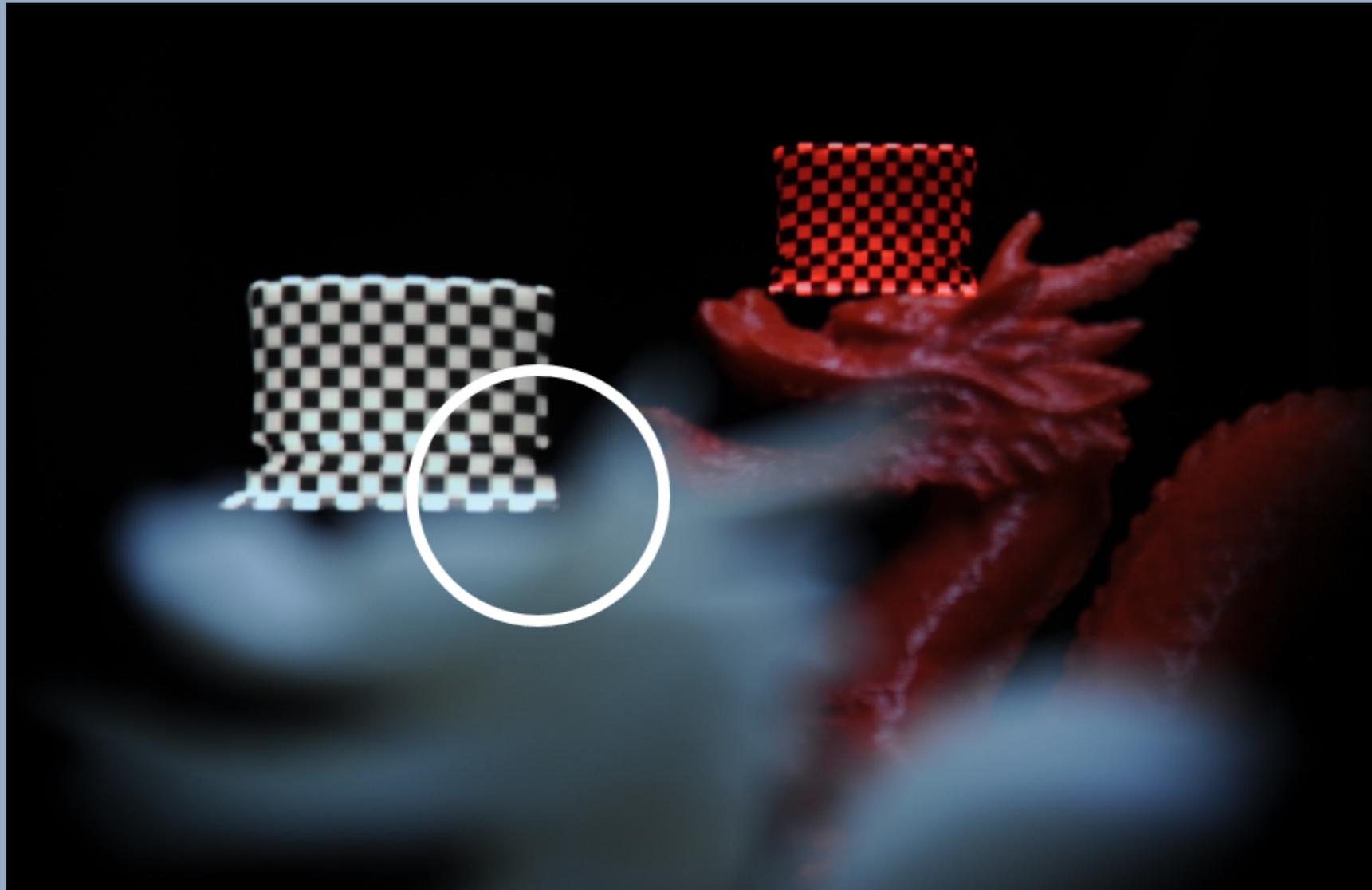
600



200



# MATCHING BLUR: REAL & VIRTUAL



MOST DISPLAYS

OUR DISPLAY

DAMIEN CONSTANTINE ROMPAPAS, AITOR ROVIRA, SEI IKEDA, ALEXANDER PLOPSKI, TAKAFUMI TAKETOMI, CHRISTIAN SANDOR, AND HIROKAZU KATO. EYE: REFOCUSABLE AUGMENTED REALITY CONTENT THROUGH EYE MEASUREMENTS. DEMO AT *IEEE INTERNATIONAL SYMPOSIUM ON MIXED AND AUGMENTED REALITY*, MERIDA, MEXICO, SEPTEMBER 2016. **BEST DEMO AWARD**

# MATCHING BLUR: REAL & VIRTUAL

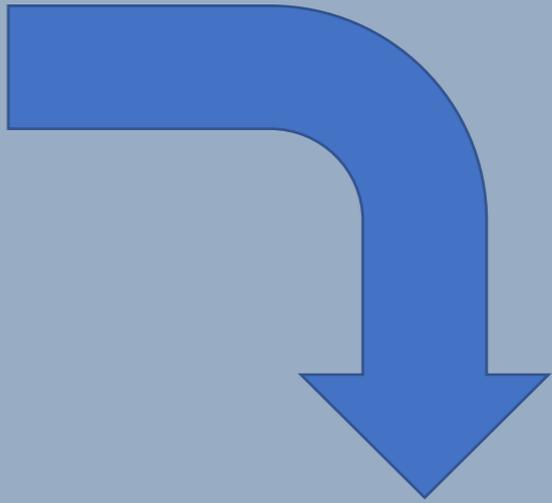


Our display prototype accurately matches the DoF of virtual objects (hats) to real objects (dragons).

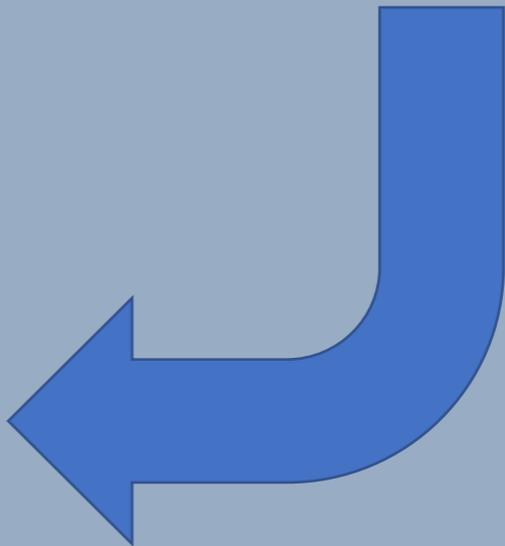
# CONCEPT OF EYEAR

Measure Eye

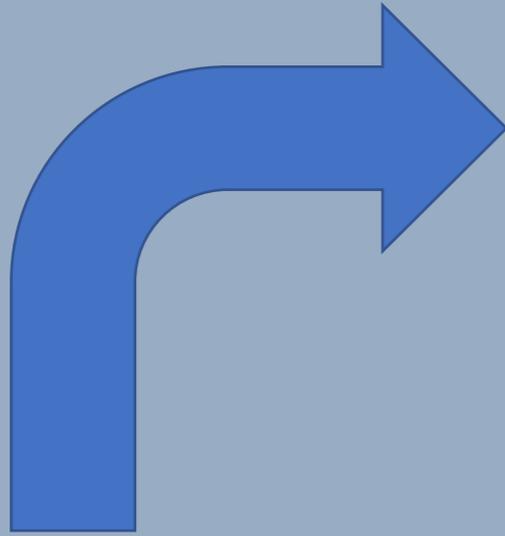
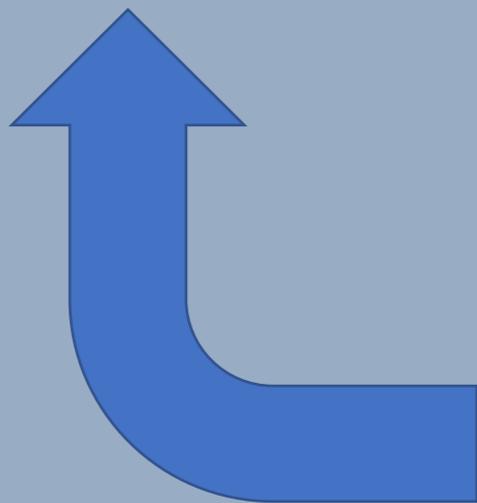
- pupil size
- focal length



Render DOF Image  
(Realtime Pathtracing  
with NVIDIA Optix)

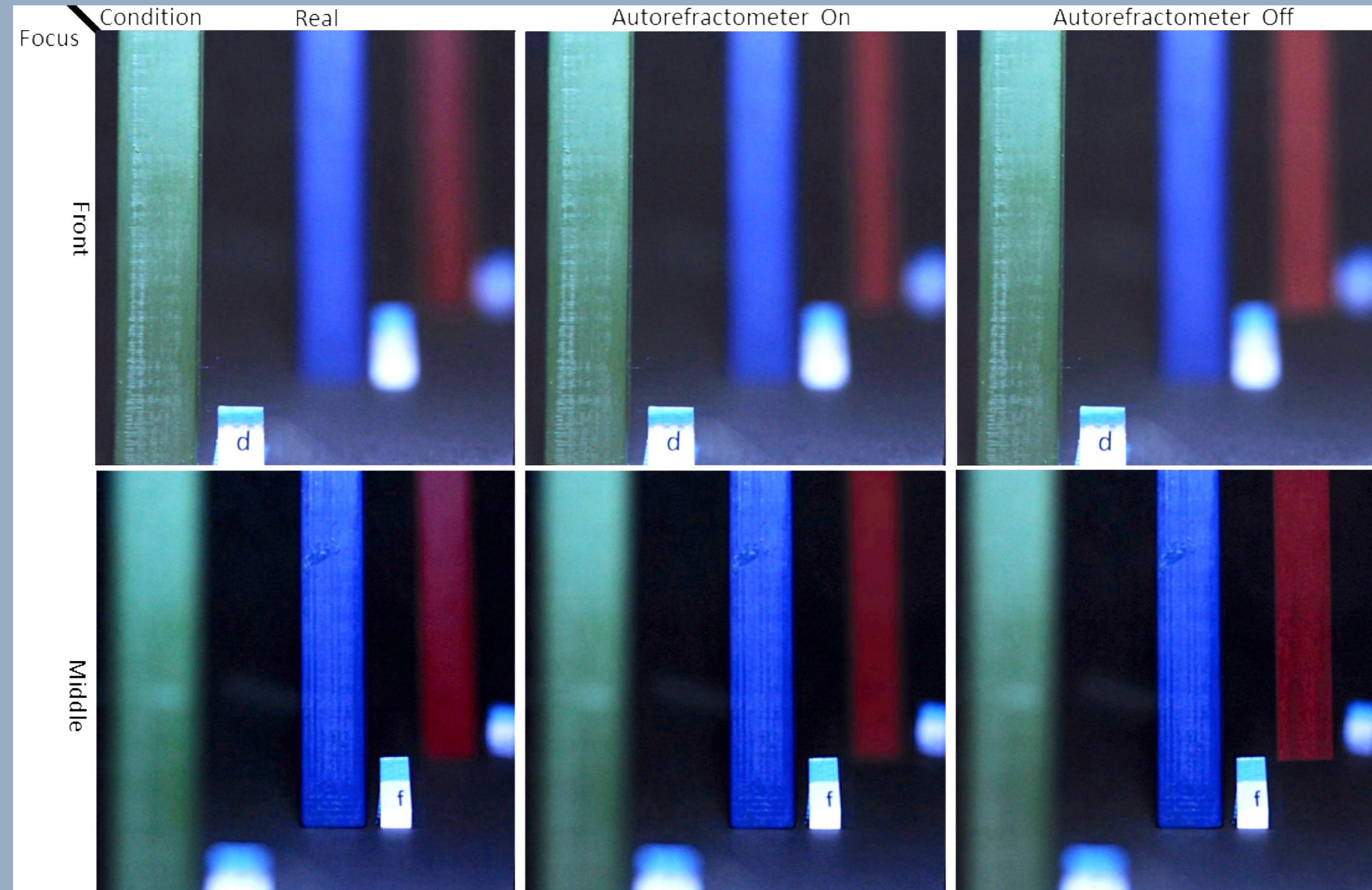


Correct Image Depth  
Difference  
(SharpView)



Display Result

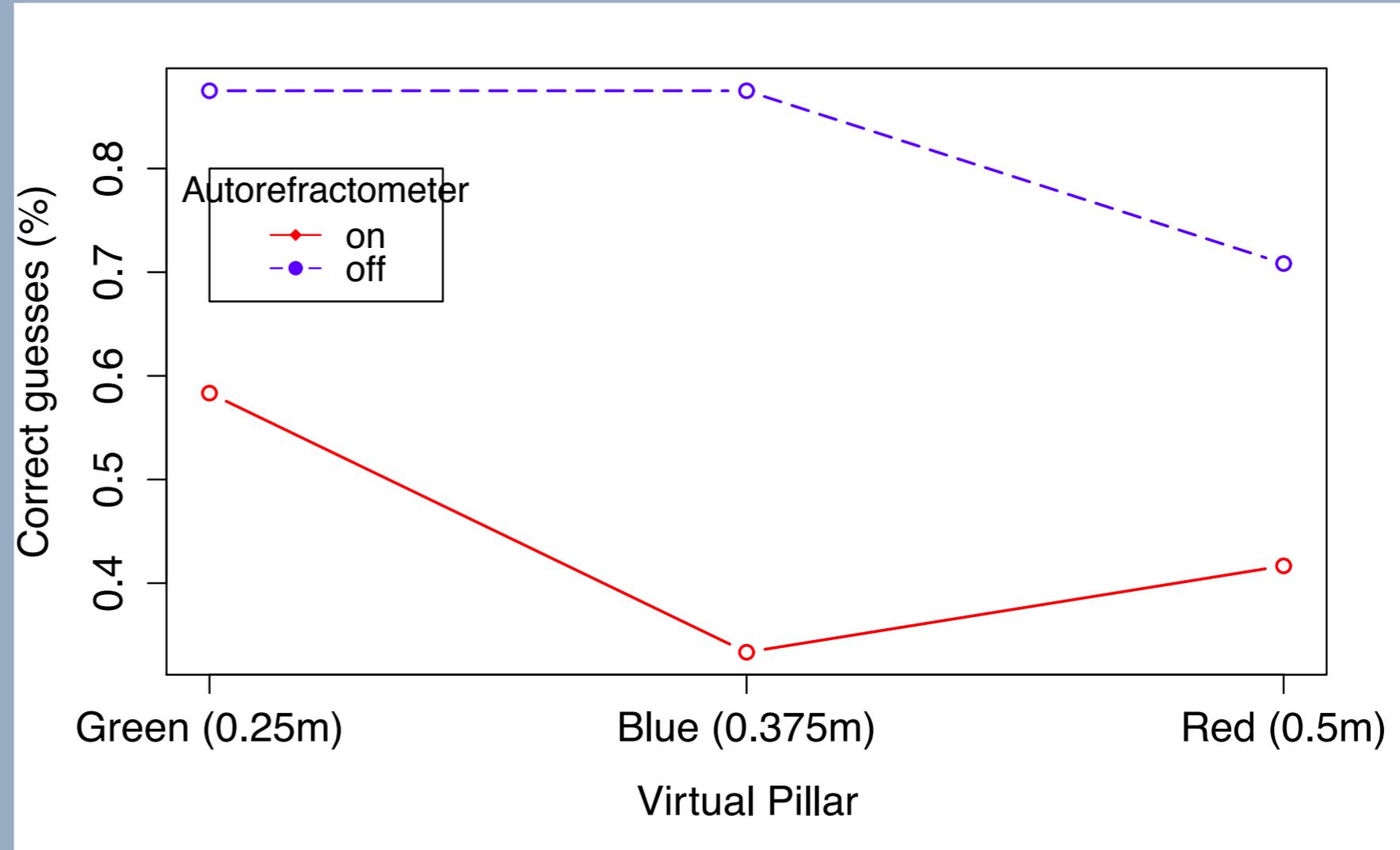
# OUR FIRST AR TURING TEST



# OUR FIRST AR TURING TEST

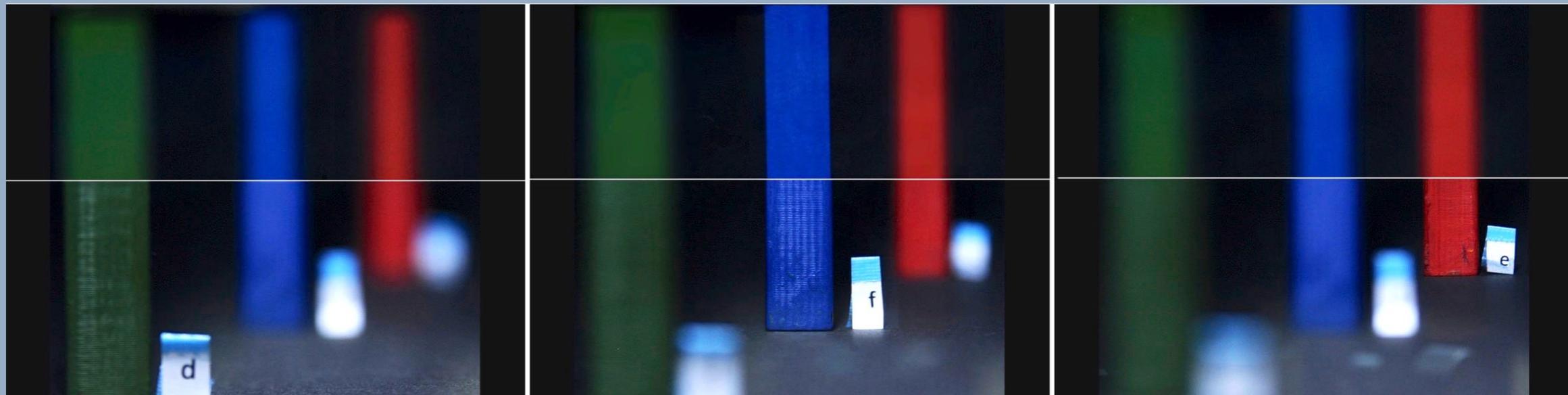
12 PARTICIPANTS

12 GUESSES



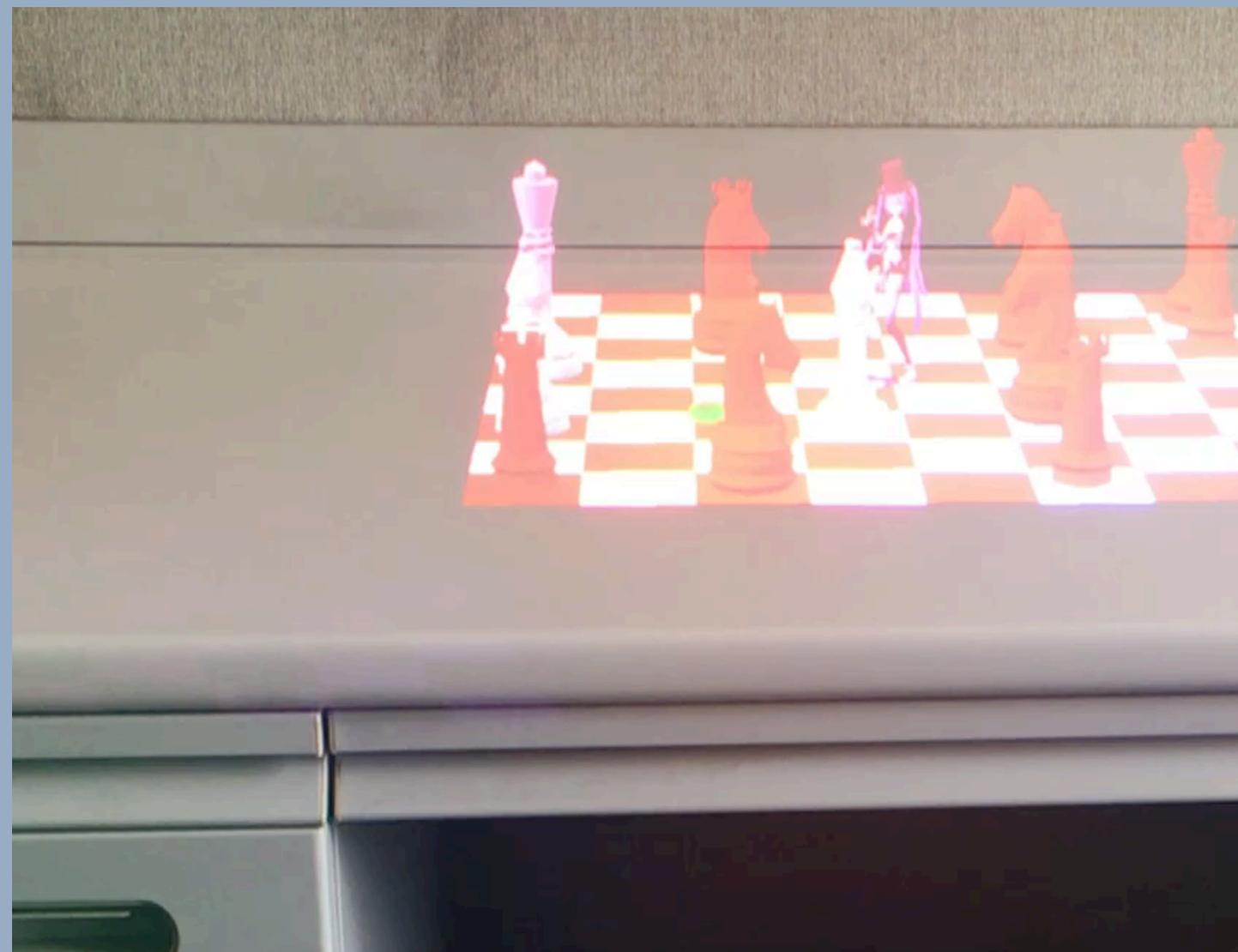
VIRTUAL

REAL



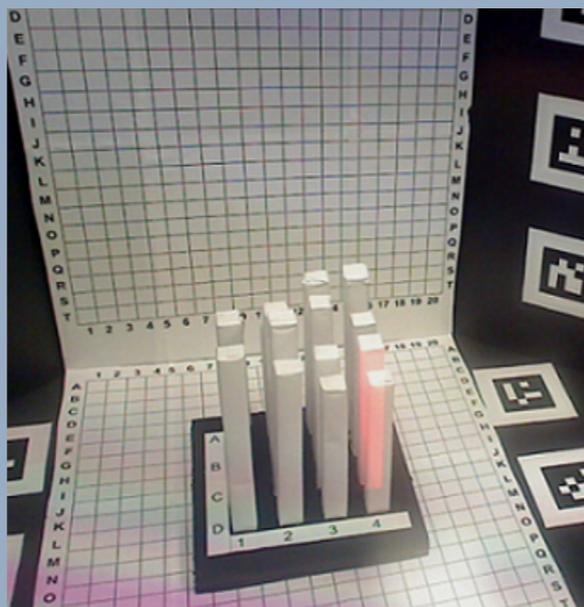
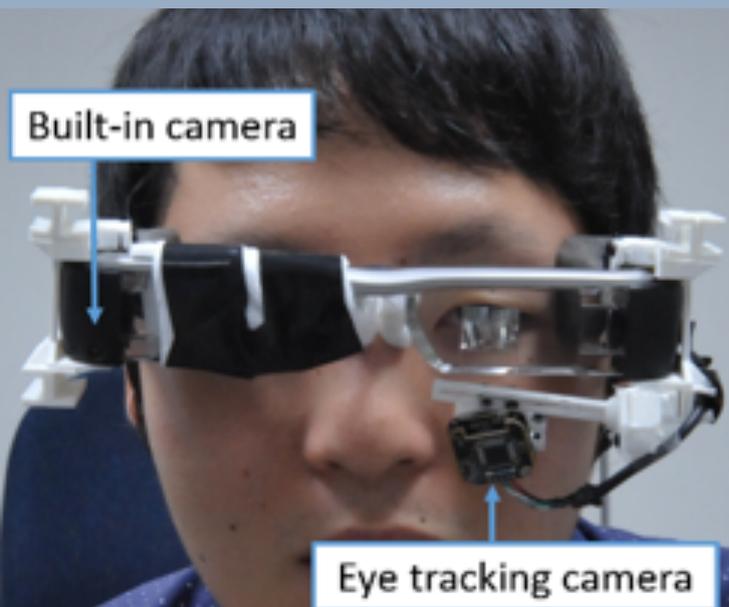
# HOLOLENS VERSION

OUR METHOD  
(EXAGGERATED BLUR)

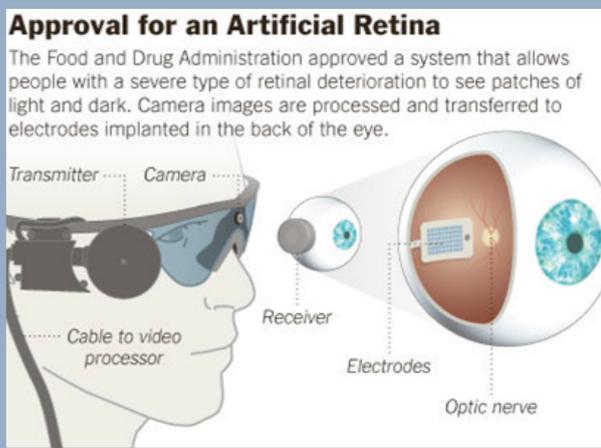
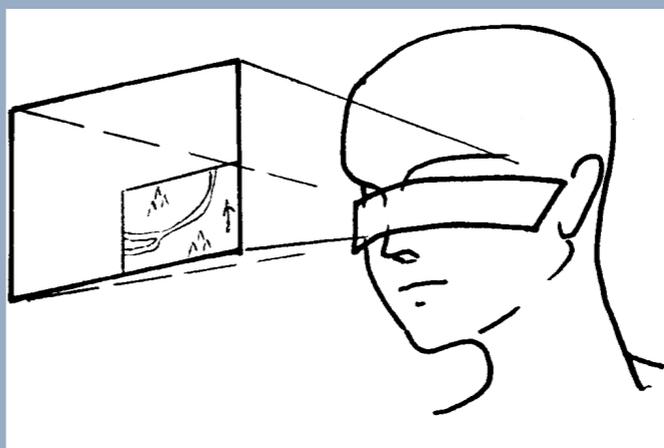
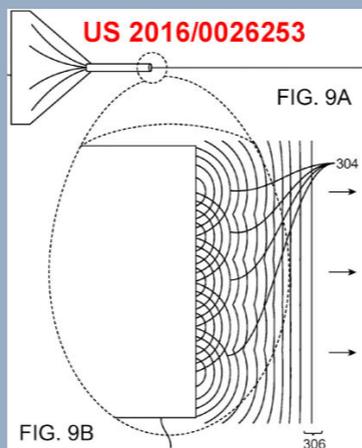
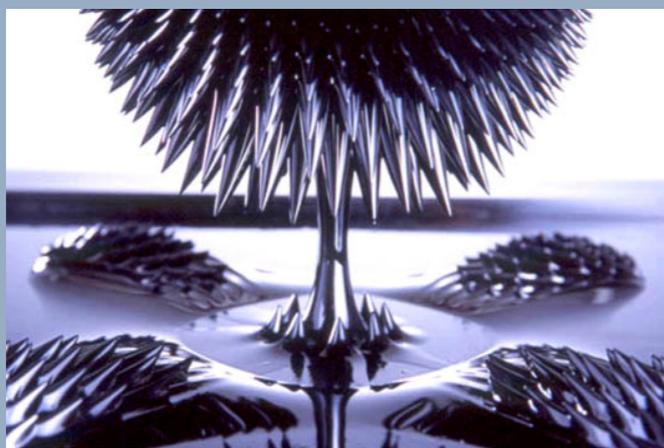
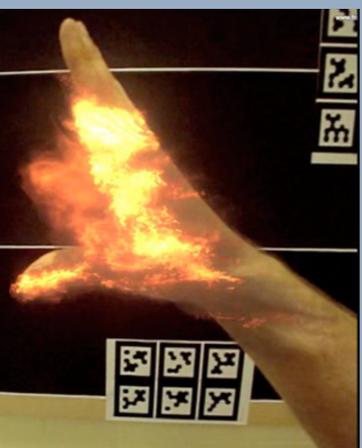


CONVENTIONAL

# DISPLAYS



# PHILOSOPHY: TRUE AUGMENTED REALITY



# TEDX ADELAIDE 2010



DEMO ONLY: [HTTPS://WWW.YOUTUBE.COM/WATCH?V=3MEALLE8KZS](https://www.youtube.com/watch?v=3MEALLE8KZS)

FULL TALK: [HTTP://WWW.YOUTUBE.COM/WATCH?V=U2YE2LHULWA](http://www.youtube.com/watch?v=U2YE2LHULWA)

SLIDES: [HTTP://WWW.SLIDESHARE.NET/CHRISTIANSANDOR/TEDX10-SANDOR](http://www.slideshare.net/Christiansandor/TEDX10-SANDOR)

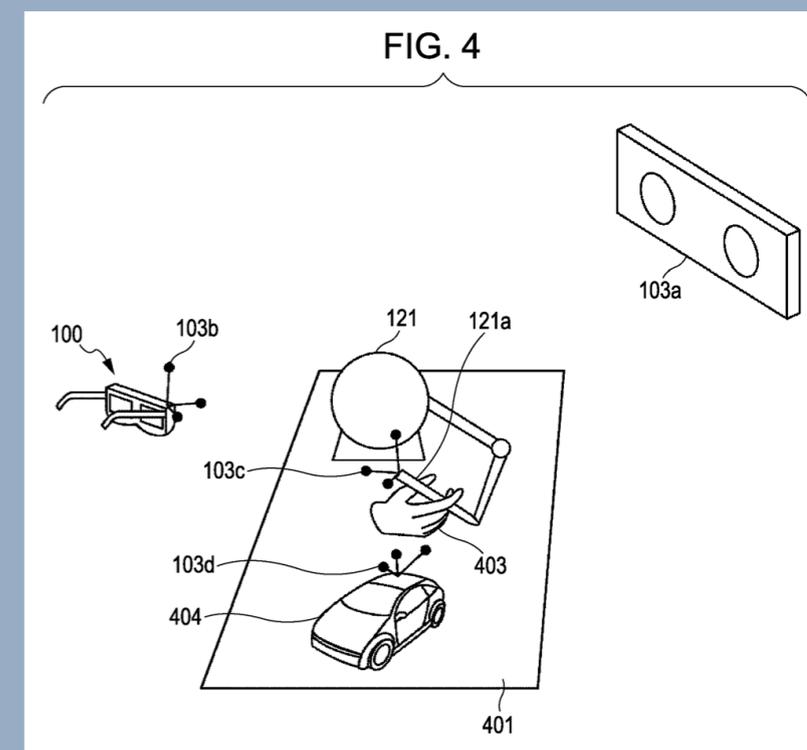
CREW

# THROUGHPUT OF HUMAN SENSES



SOURCE: DAVID MCCANDLESS'S TED TALK (2010)

# RESEARCH IN CANON



CHRISTIAN SANDOR, TSUYOSHI KUROKI, AND SHINJI UCHIYAMA. INFORMATION PROCESSING METHOD AND DEVICE FOR PRESENTING HAPTICS RECEIVED FROM A VIRTUAL OBJECT. *JAPANESE PATENT* 2006117732 (FILED 4/2006). *PATENT IN CHINA, EUROPE, AND US* 8,378,997 (FILED 19 APRIL 2007). [HTTP://GOO.GL/V3DAX](http://goo.gl/v3dax)

# RESEARCH IN CANON



CHRISTIAN SANDOR, SHINJI UCHIYAMA, AND HIROYUKI YAMAMOTO. VISUO-HAPTIC SYSTEMS: HALF-MIRRORS CONSIDERED HARMFUL. IN *PROCEEDINGS OF THE IEEE WORLD HAPTICS CONFERENCE*, PAGES 292–297. IEEE, MARCH 2007. TSUKUBA, JAPAN.

# Visuo-Haptic Augmented Reality Demo for TEDx

Team: Christian Sandor – Ulrich Eck  
Quang Le – Peter Weir  
Donald Urquhart

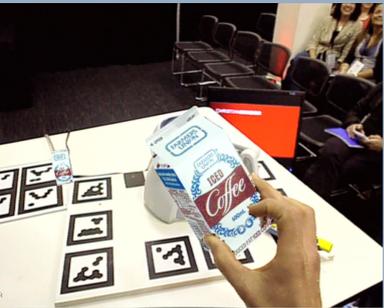
# LARGE SCALE HAPTICS DISPLAY AT NAIST (UNPUBLISHED)



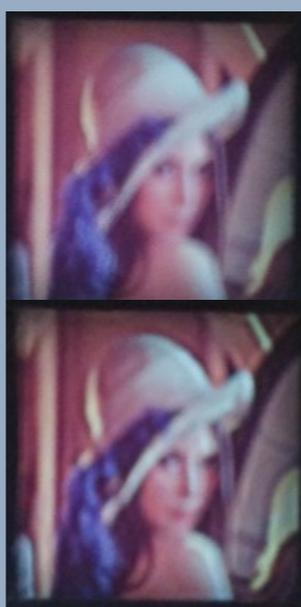
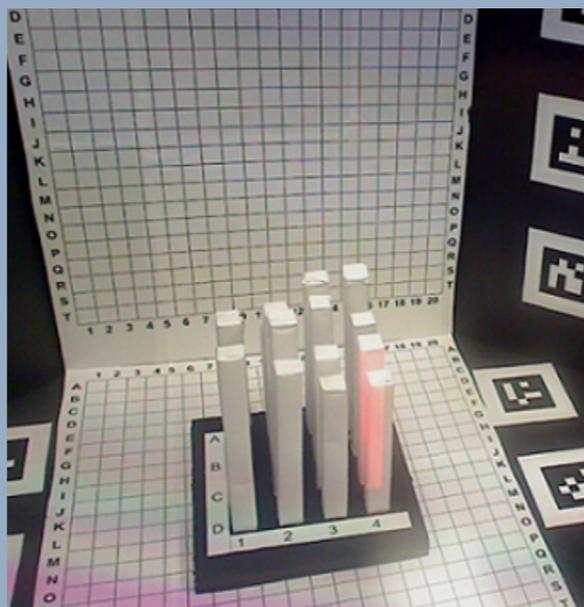
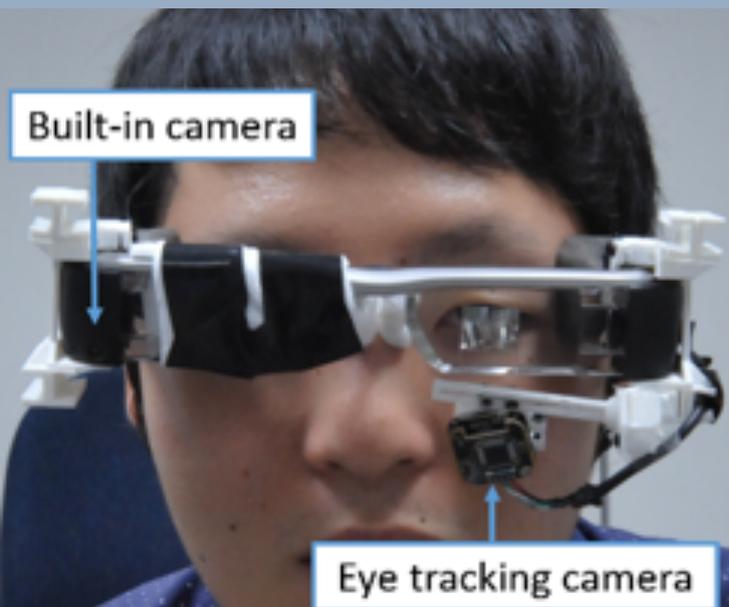




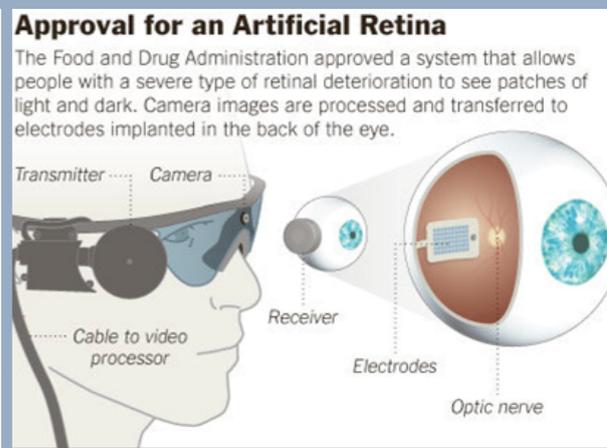
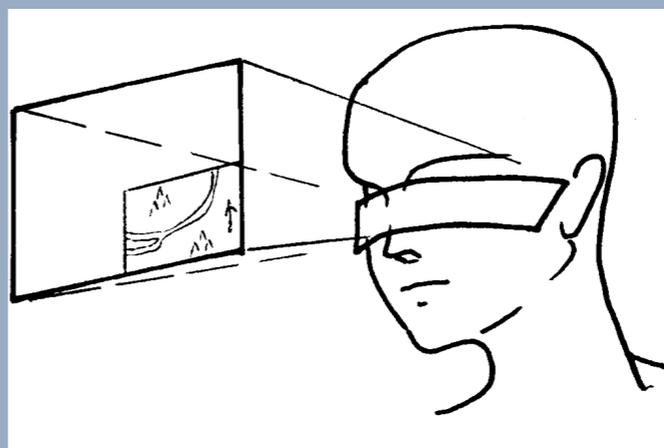
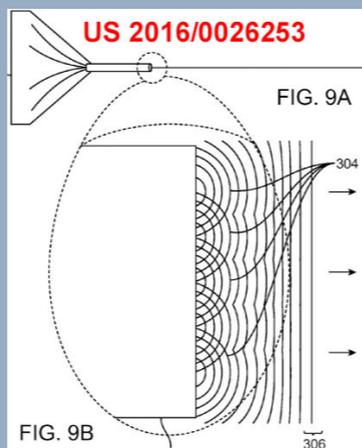
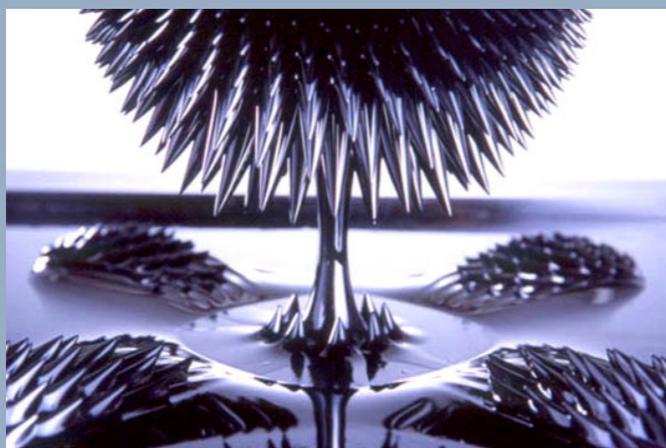
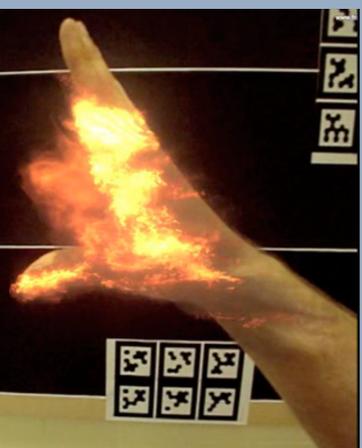
# DISPLAYS



# APPLICATIONS



# PHILOSOPHY: TRUE AUGMENTED REALITY



# EDGE-BASED X-RAY



BENJAMIN AVERY, CHRISTIAN SANDOR, BRUCE H. THOMAS. IMPROVING SPATIAL PERCEPTION FOR AUGMENTED REALITY X-RAY VISION. IN *PROCEEDINGS OF THE IEEE VIRTUAL REALITY CONFERENCE*, PAGES 79–82. IEEE, MARCH 2009. LAFAYETTE, LOUISIANA, USA.



- Background  
GM
- Foreground  
Edges
- 1  
Building
- 2  
Building

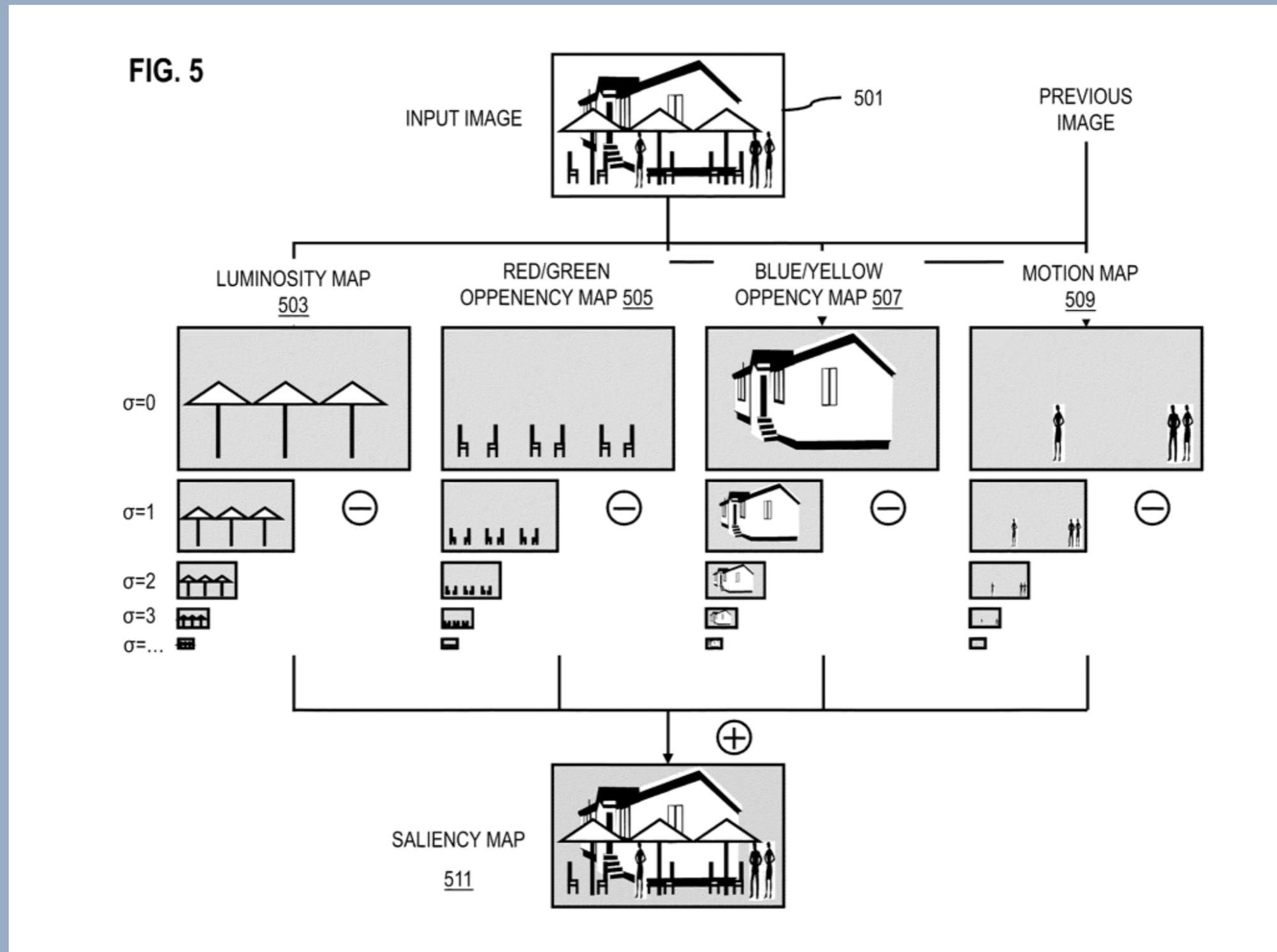
- Background  
GM
- 1  
Ladder
- 2  
Building
- 3  
Ladder  
Warning

# SALIENCY X-RAY



CHRISTIAN SANDOR, ANDREW CUNNINGHAM, ARINDAM DEY, AND VILLE-VEIKKO MATTILA. AN AUGMENTED REALITY X-RAY SYSTEM BASED ON VISUAL SALIENCY. IN *PROCEEDINGS OF THE IEEE INTERNATIONAL SYMPOSIUM ON MIXED AND AUGMENTED REALITY*, PAGES 27–36, SEOUL, KOREA, OCTOBER 2010.

# SALIENCY X-RAY



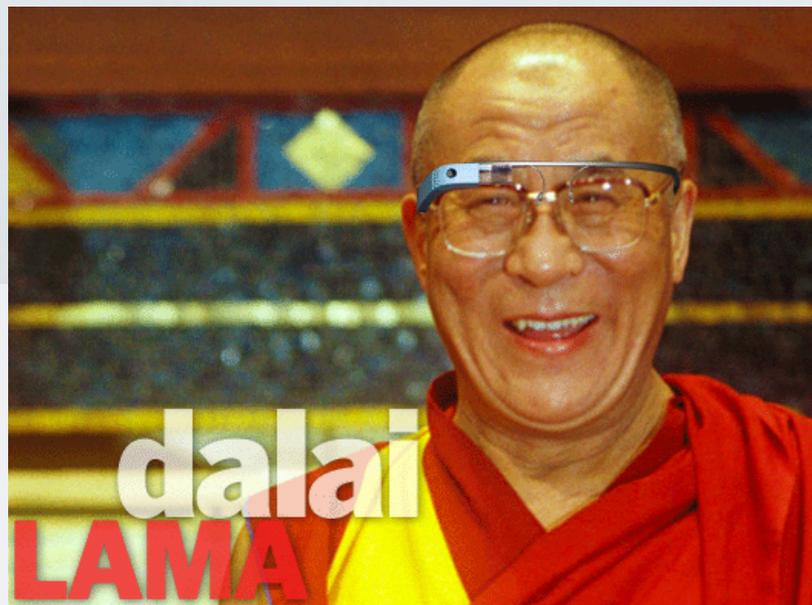
CHRISTIAN SANDOR, ANDREW CUNNINGHAM, AND MATTILA VILLE-VEIKKO.  
METHOD AND APPARATUS FOR AN AUGMENTED REALITY X-RAY. *US PATENT APPLICATION 12/785,170* (FILED 21 MAY 2010). [HTTP://GOO.GL/NCVZJ](http://goo.gl/NCVZJ)

# MELTING



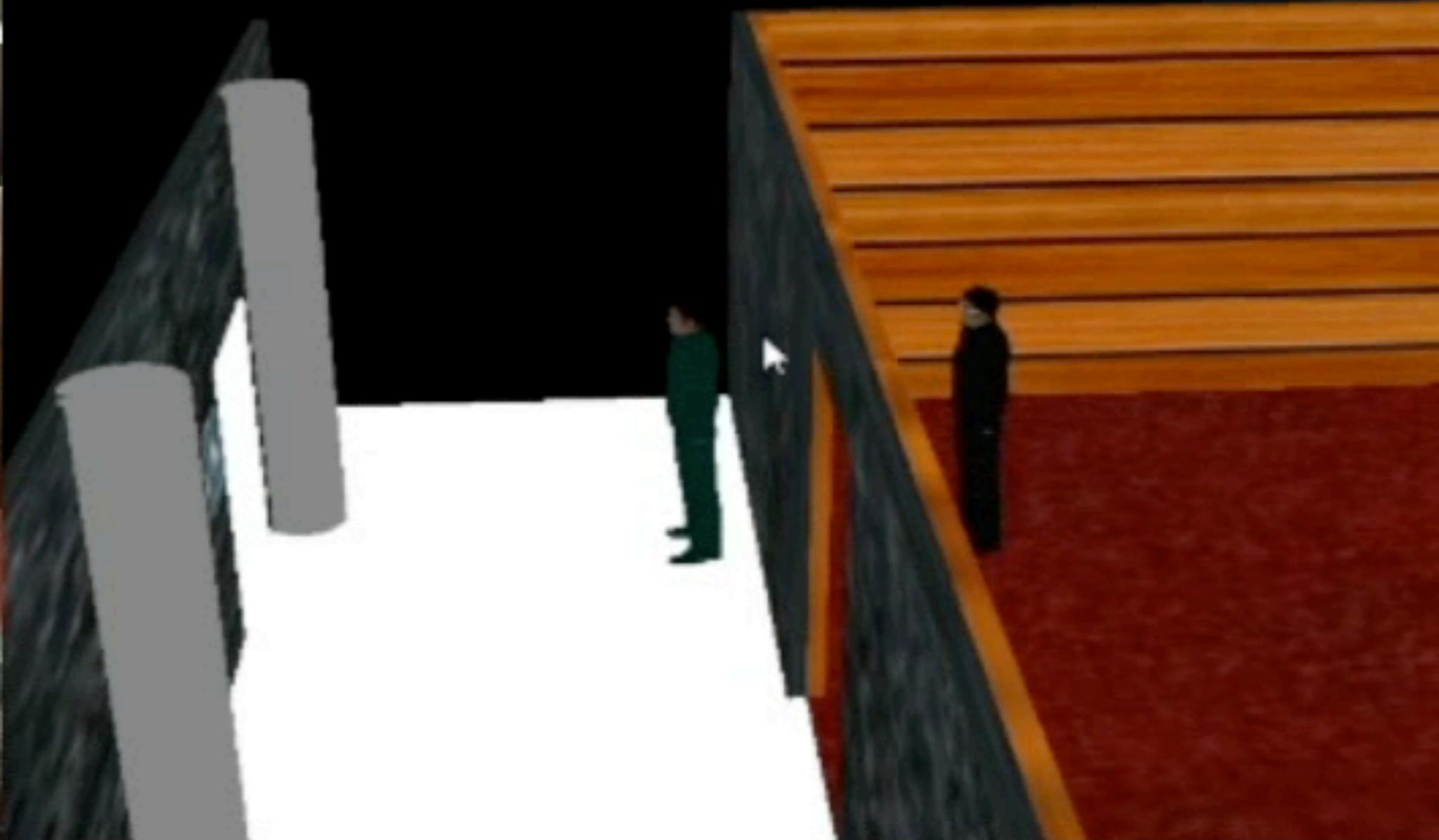
CHRISTIAN SANDOR, ANDREW CUNNINGHAM, ULRICH ECK, DONALD URQUHART, GRAEME JARVIS, ARINDAM DEY, SEBASTIEN BARBIER, MICHAEL R. MARNER, SANG RHEE. EGOCENTRIC SPACE-DISTORTING VISUALIZATIONS FOR RAPID ENVIRONMENT EXPLORATION IN MOBILE MIXED REALITY. IN *PROCEEDINGS OF THE IEEE VIRTUAL REALITY CONFERENCE*, PAGES 47–50, WALTHAM, MA, USA, MARCH 2010.

# AUGMENTED REALITY X-RAY FOR GOOGLE GLASS



GOOGLE FACULTY AWARD (2014)

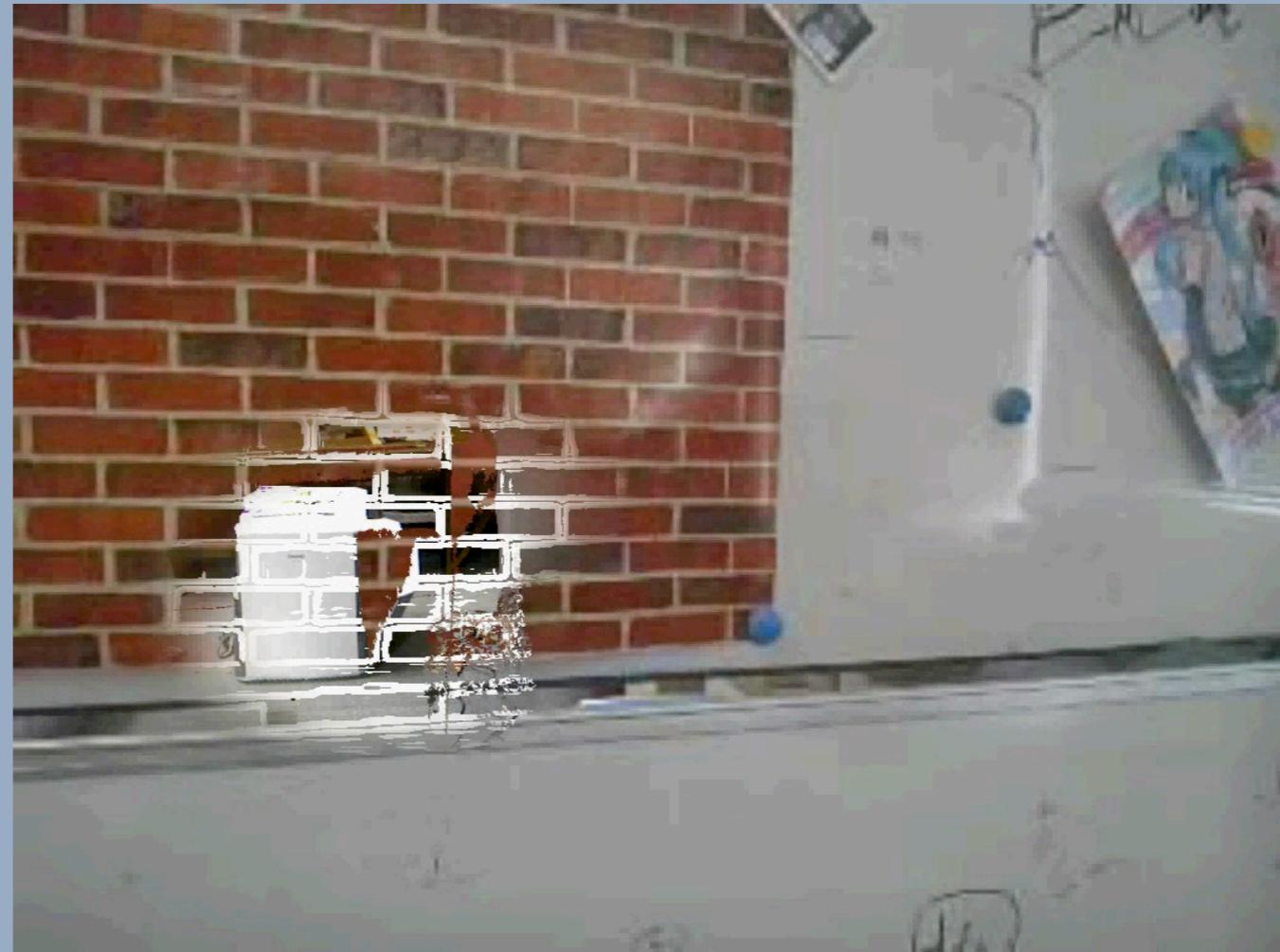
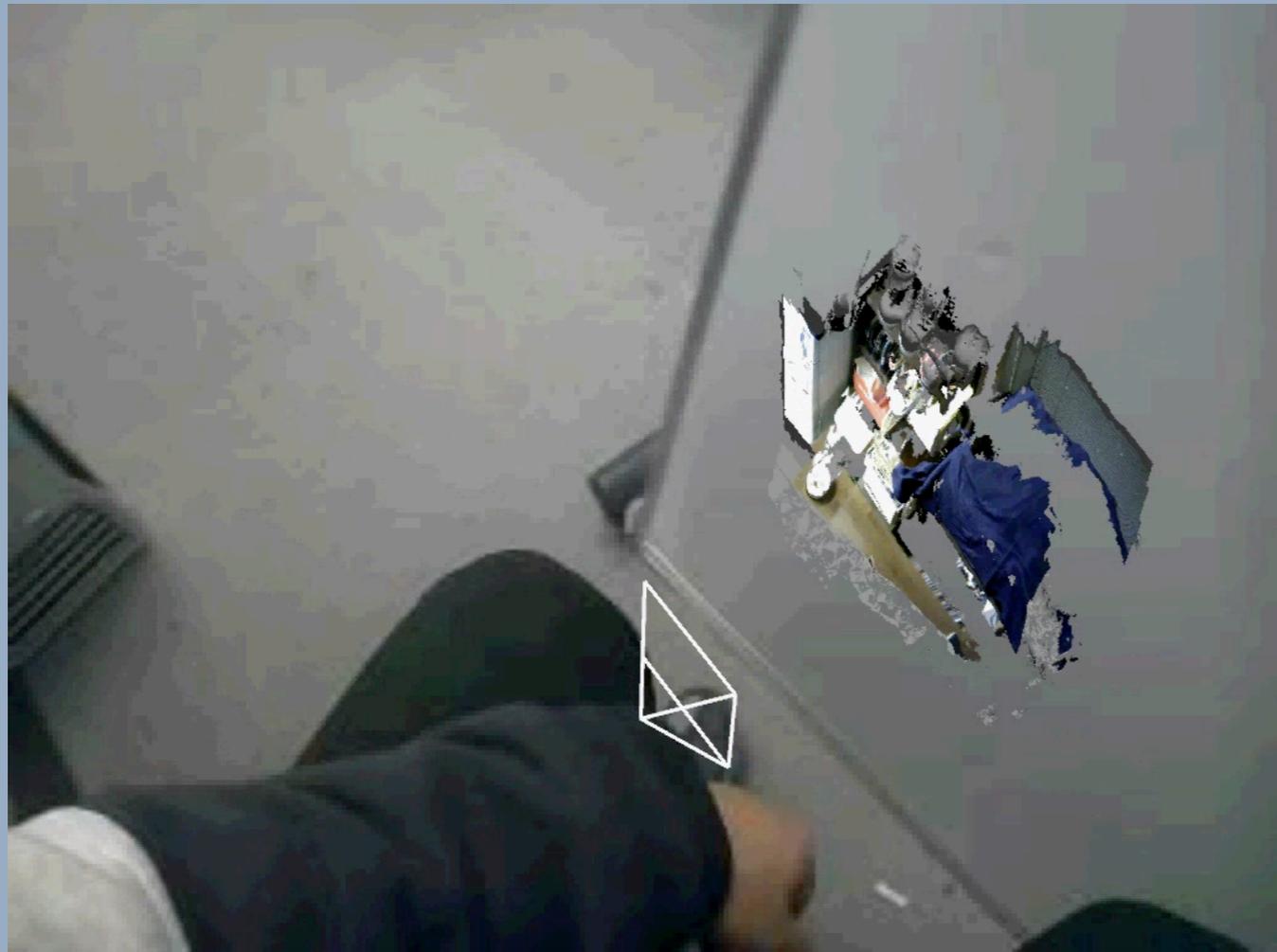
# DEMO AT SIGGRAPH ASIA (12/2014)



# FINAL DEMO (4/2015)



# FINAL DEMO (4/2015)



# FUTURE WORK: MEDICAL APPLICATIONS

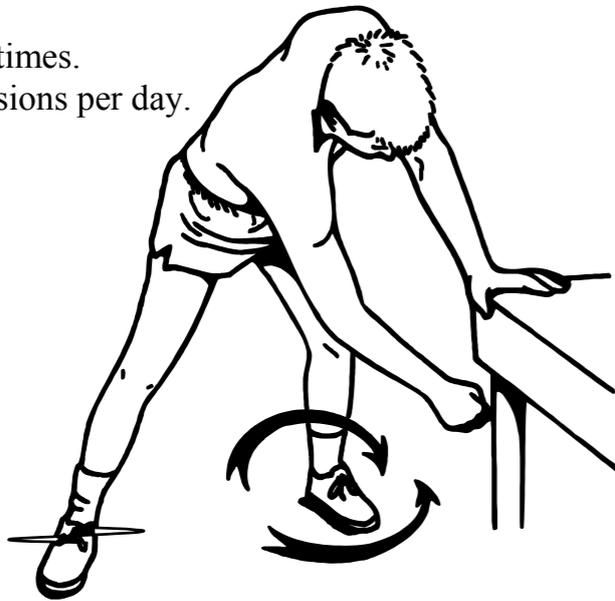


## Rehabilitation & Sports Medicine Frozen Shoulder

SHOULDER - 26  
Range of Motion Exercises:  
Pendulum (Circular)

Let arm move in a circle clockwise, then counter-clockwise, by rocking body weight in a circular pattern.

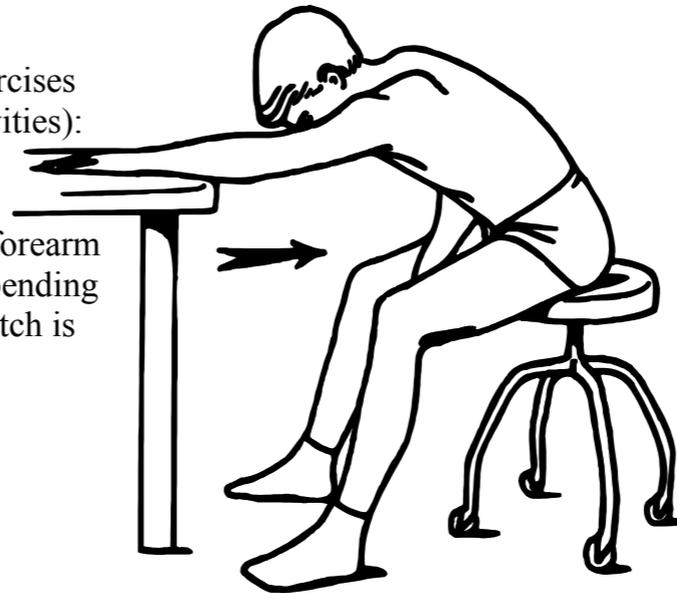
Repeat 10 times.  
Do 3-5 sessions per day.



SHOULDER - 7  
Range of Motion Exercises  
(Self-Stretching Activities):  
Flexion

Sitting upright, slide forearm forward along table, bending from waist until a stretch is felt. Hold 30 seconds.

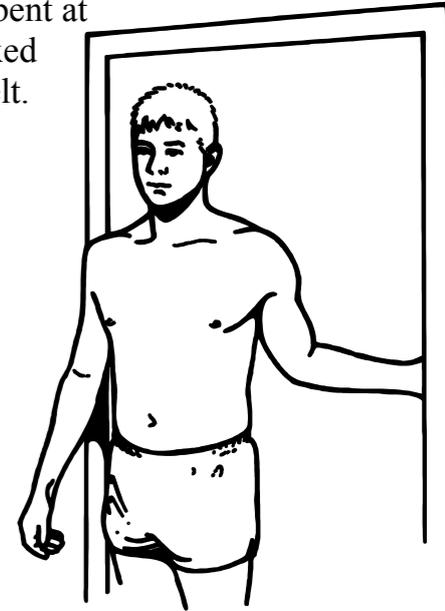
Repeat 1-4 times  
Do 1 session per day.



SHOULDER - 11  
Range of Motion Exercises  
(Self-Stretching Activities):  
External Rotation (alternate)

Keep palm of hand against door frame, and elbow bent at 90°. Turn body from fixed hand until a stretch is felt. Hold 30 seconds.

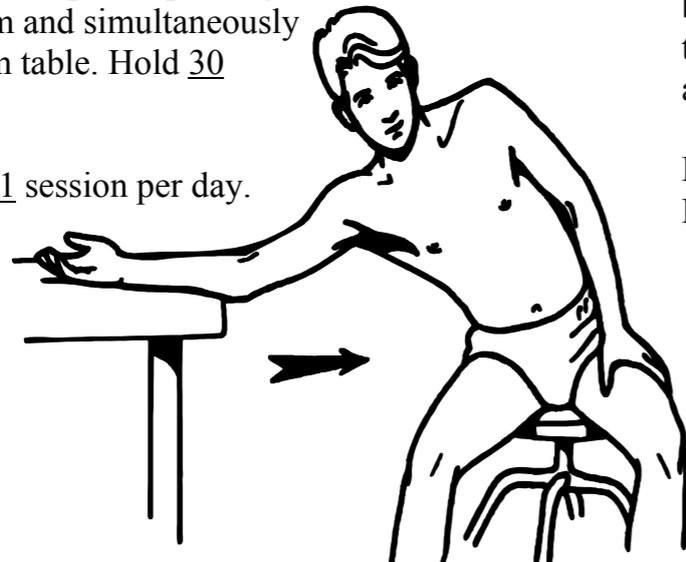
Repeat 1-4 times  
Do 1 session per day.



SHOULDER - 9  
Range of Motion Exercises (Self-Stretching Activities):  
Abduction

With arm resting on table, palm up, bring head down toward arm and simultaneously move trunk away from table. Hold 30 seconds.

Repeat 1-4 times Do 1 session per day.



SHOULDER - 73  
Towel Stretch for Internal Rotation

Pull involved arm up behind back by pulling towel upward with other arm. Hold 30 seconds.

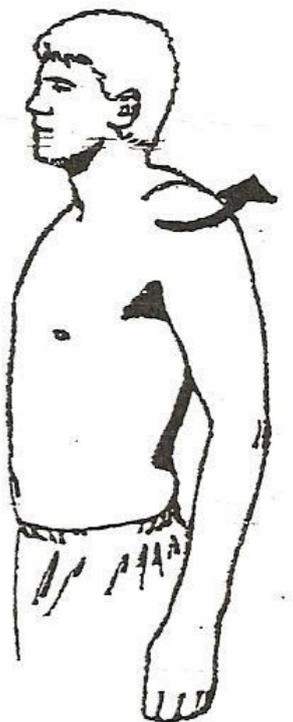
Repeat 1-4 times  
Do 1 session per day.



SCAP SETS

Pull your shoulders back, pinching the shoulder blades together. Do not let the shoulders come forward. Hold 5-10 seconds.

Repeat 10 times  
Do 1 session per day.

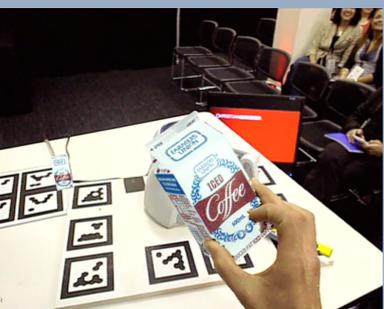


# FUTURE WORK: MEDICAL APPLICATIONS

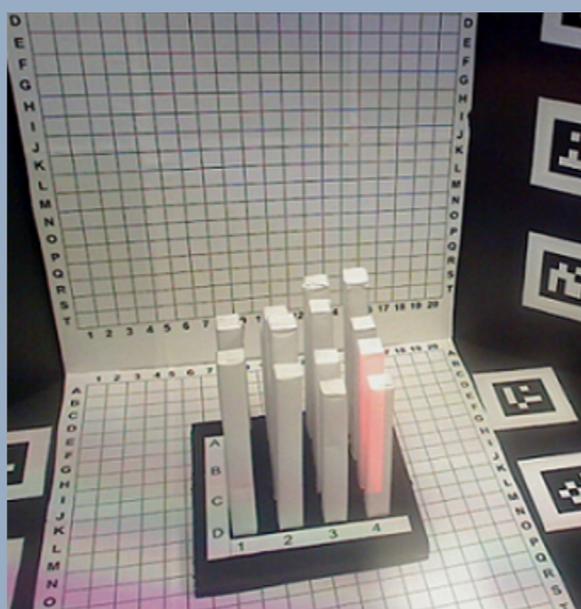
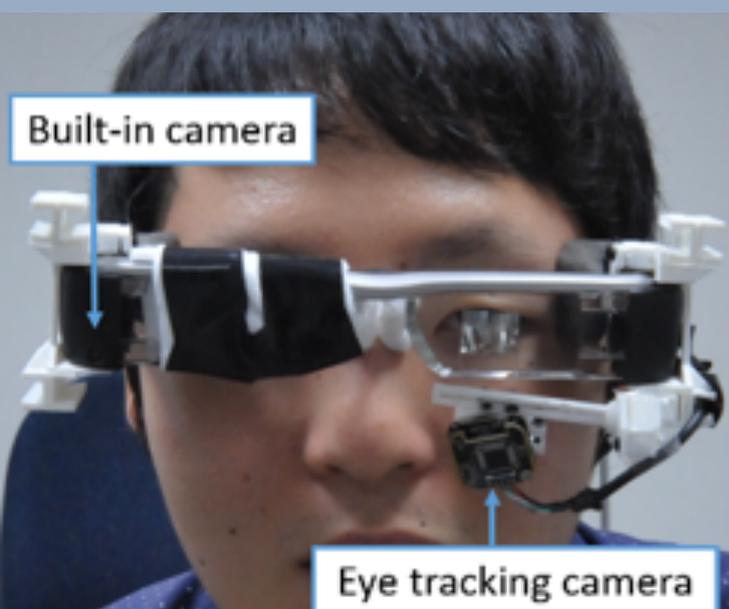


COURTESY OF [HTTP://CAMPAR.IN.TUM.DE/MAIN/FELIXBORK](http://campar.in.tum.de/main/felixbork)

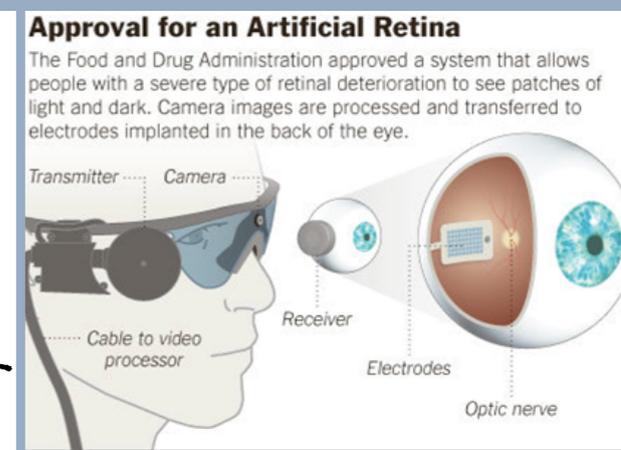
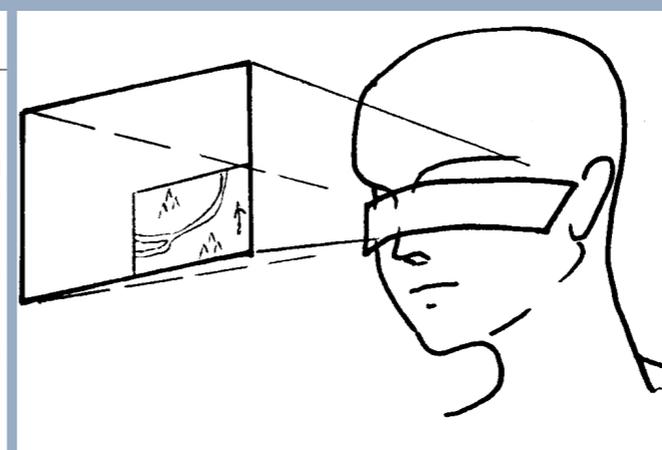
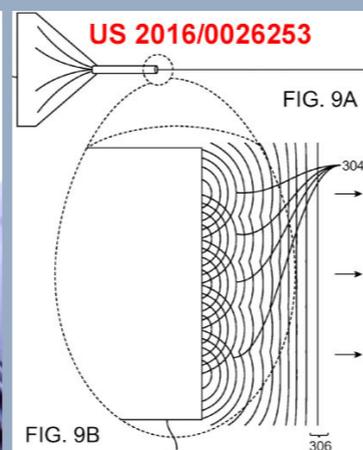
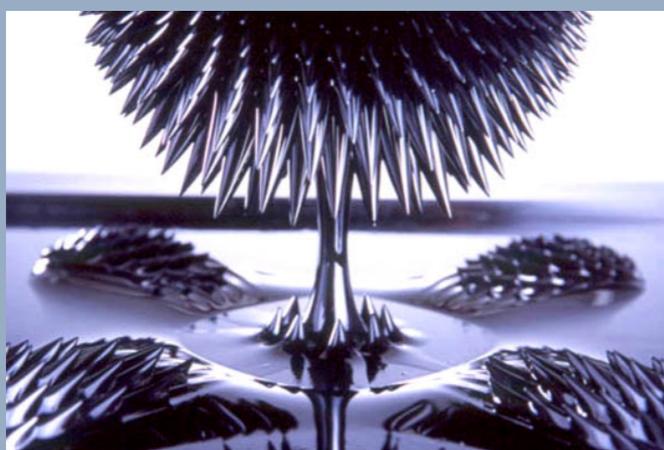
# DISPLAYS



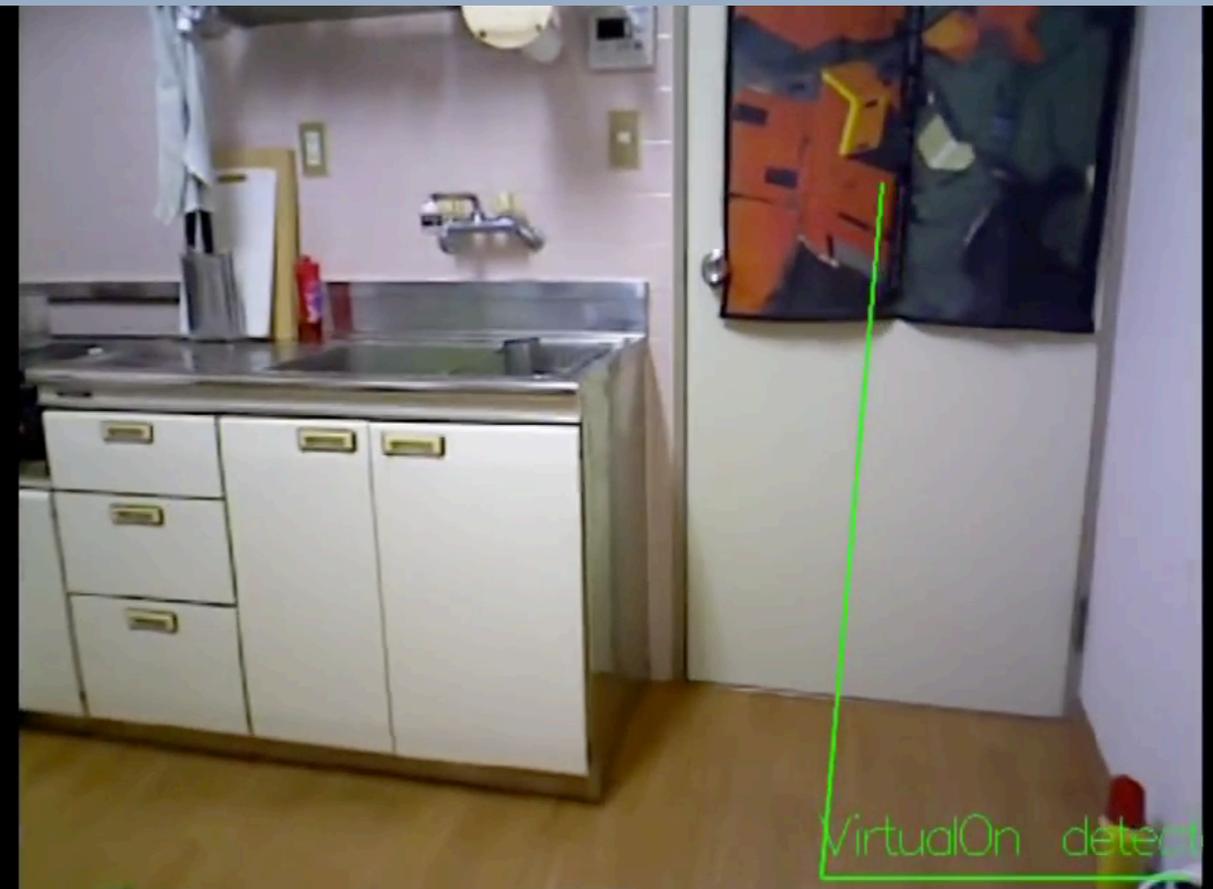
# APPLICATIONS



# PHILOSOPHY: TRUE AUGMENTED REALITY



# TRANSMEDIA CINEMATOGRAPHY



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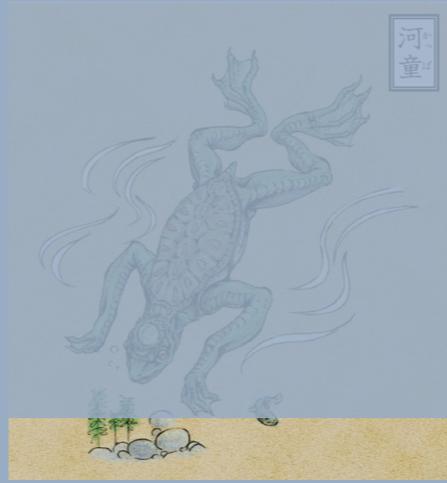
# YŌKAI (妖怪)



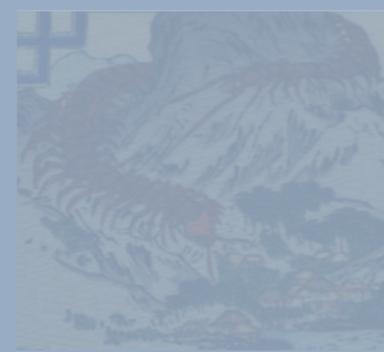
Nurikabe



Long neck woman



Kappa



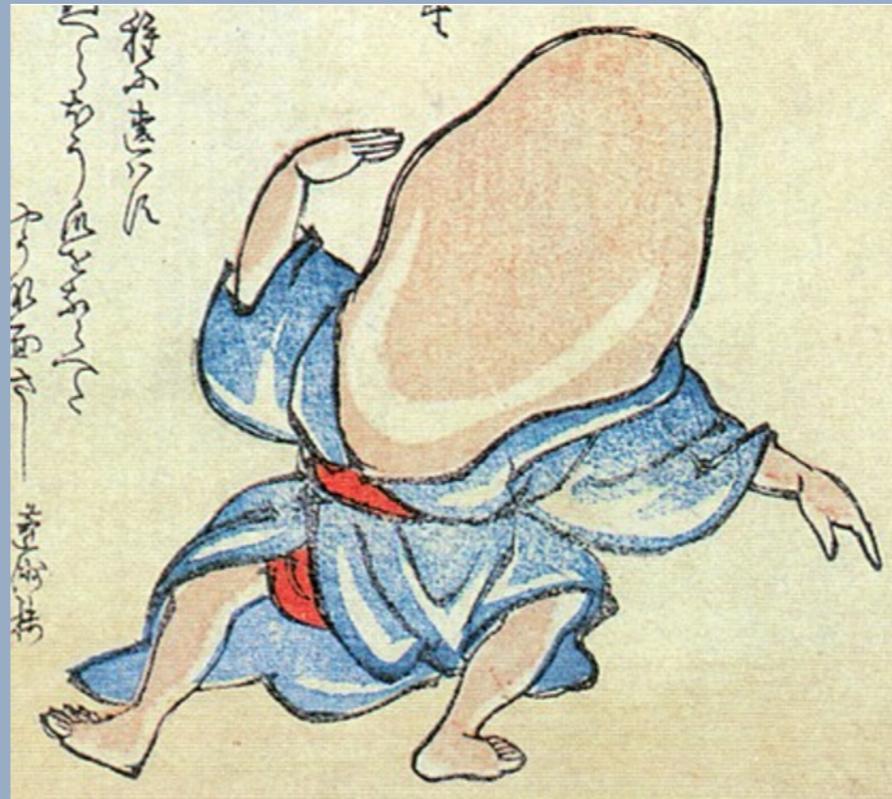
Big centipede



Tengu



Mokumokuren



Nopperabou



Nurarihyon



Tsuchigumo



Paper umbrella haunted



Umibouzu



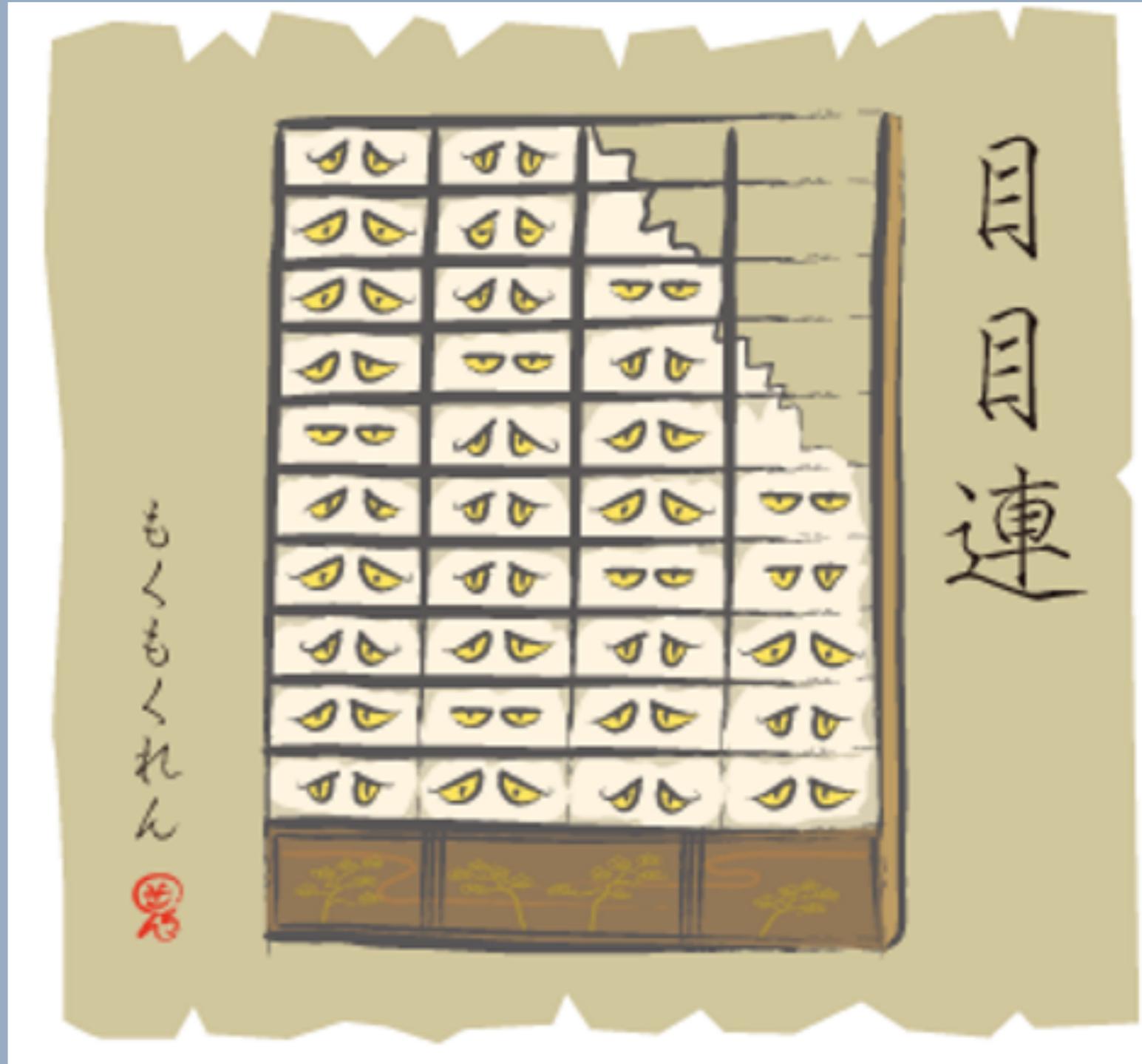
Gasyadokuro

# AR YŌKAI (UNPUBLISHED)





Big centipede



Mokumokuren

