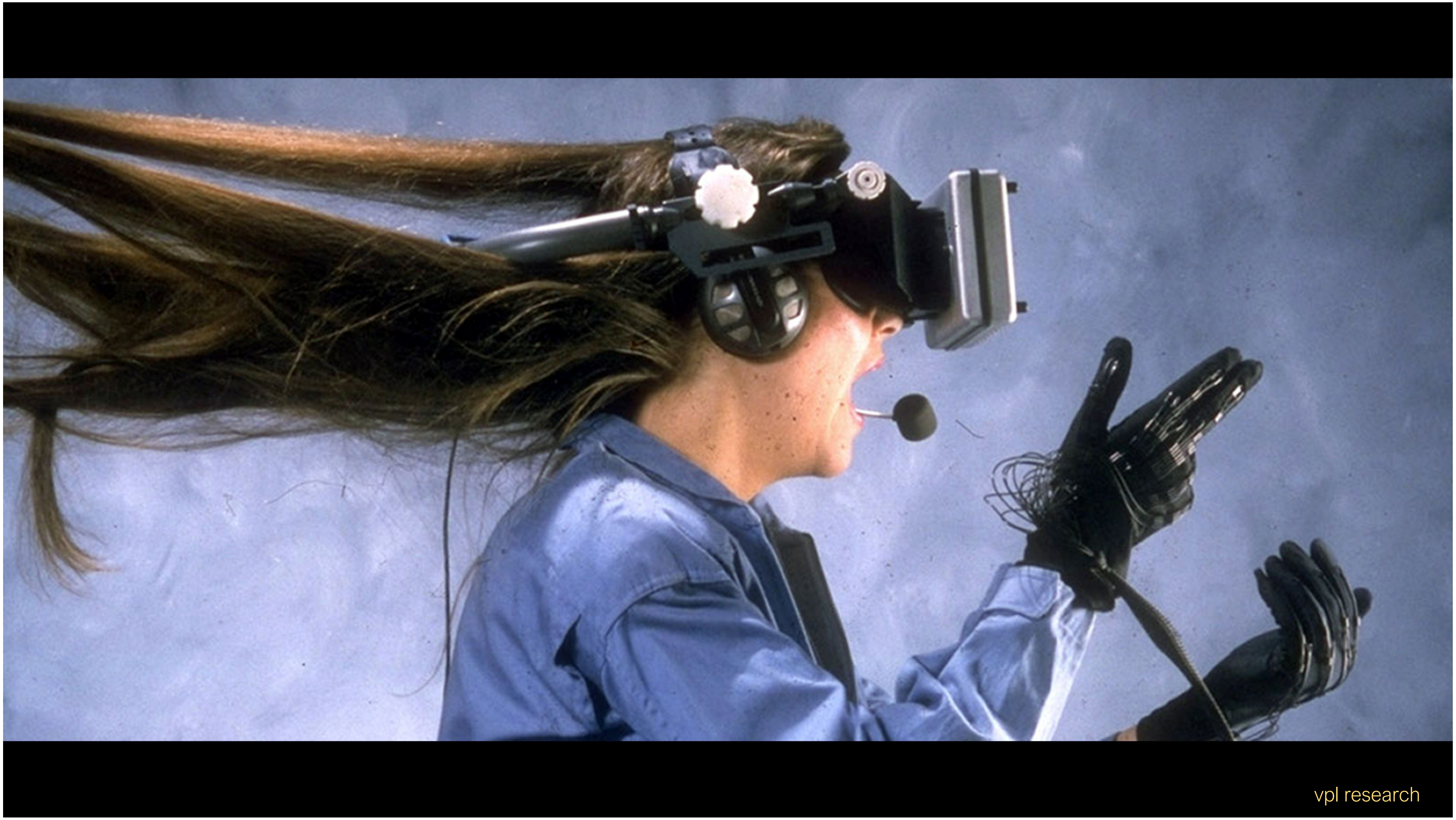
UNIVERSITY OF CAMBRIDGE
COMPUTER LABORATORY
RAINBOW GRAPHICS GROUP

Advanced Graphics & Image Processing

Virtual and Augmented Reality

Part 1/4 – virtual reality

Rafał Mantiuk
Dept. of Computer Science and Technology, University of Cambridge


vpl research

simulation & training

visualization & entertainment

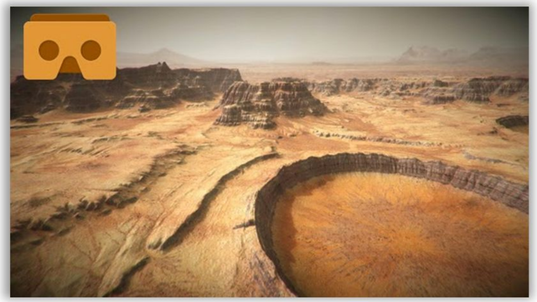
remote control of vehicles, e.g. drones

gaming

robotic surgery

architecture walkthroughs

education

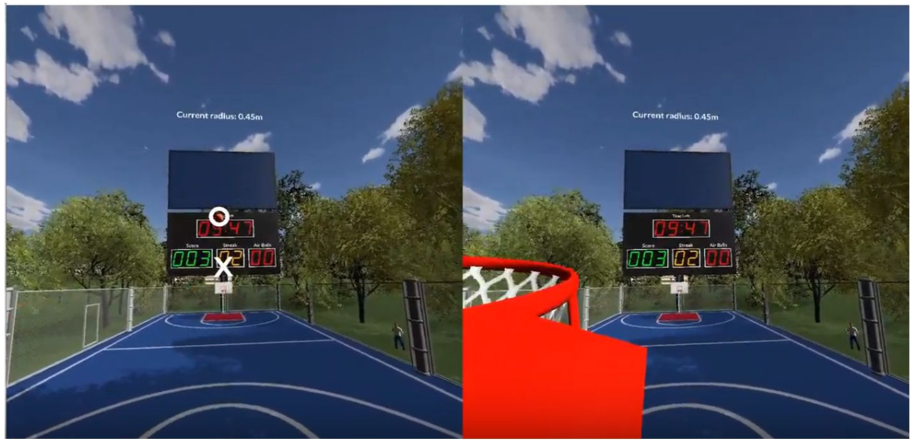


virtual travel

a trip down the rabbit hole

Vision treatment in VR

- Treatment of amblyopia
  - Training the brain to use the "lazy" eye



Images courtesy of VIVID VISION

Exciting Engineering Aspects of VR/AR

- cloud computing
- shared experiences

- compression, streaming

- CPU, GPU
- IPU, DPU?

- sensors & imaging
- computer vision
- scene understanding

images by microsoft, facebook

- VR cameras

- photonics / waveguides
- human perception
- displays: visual, auditory, vestibular, haptic, …

- HCI
- applications

Where We Want It To Be

image by ray ban

Personal Computer
e.g. Commodore PET 1983

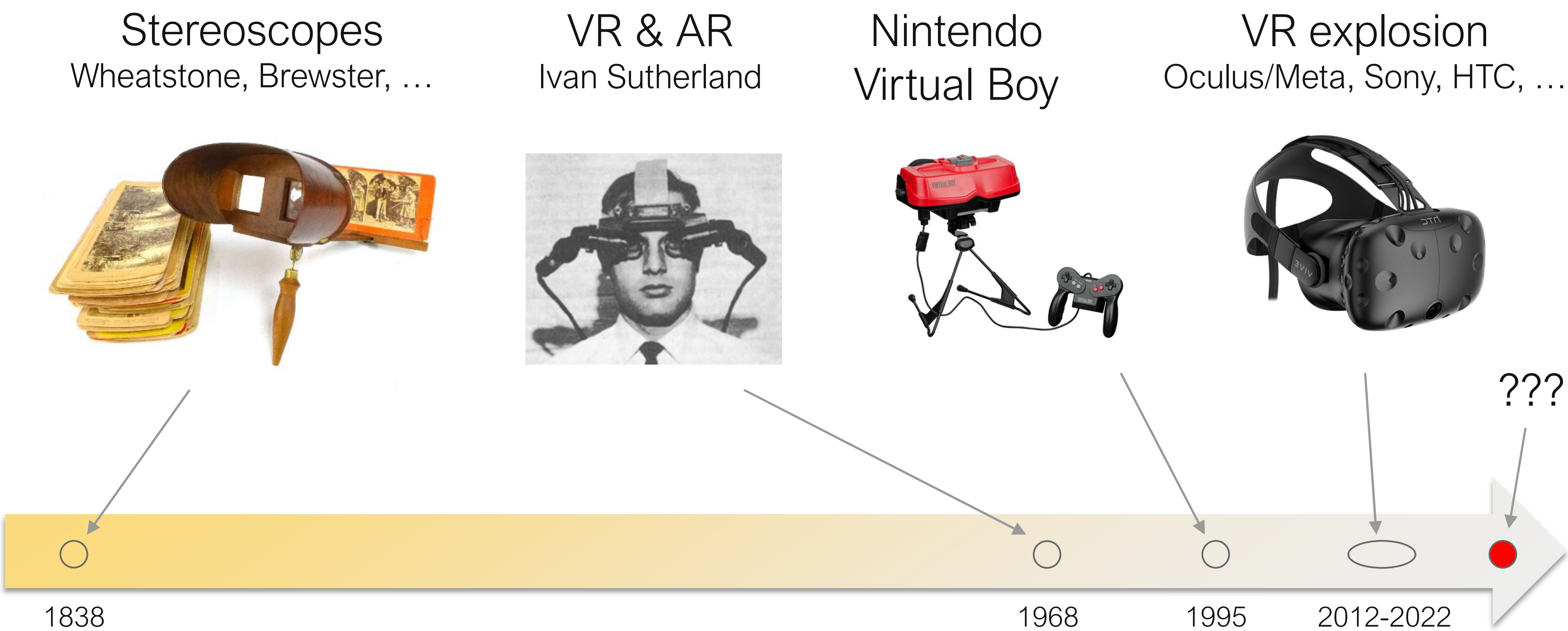
Laptop
e.g. Apple MacBook

Smartphone
e.g. Google Pixel

AR/VR
e.g. Microsoft Hololens

???

A Brief History of Virtual Reality



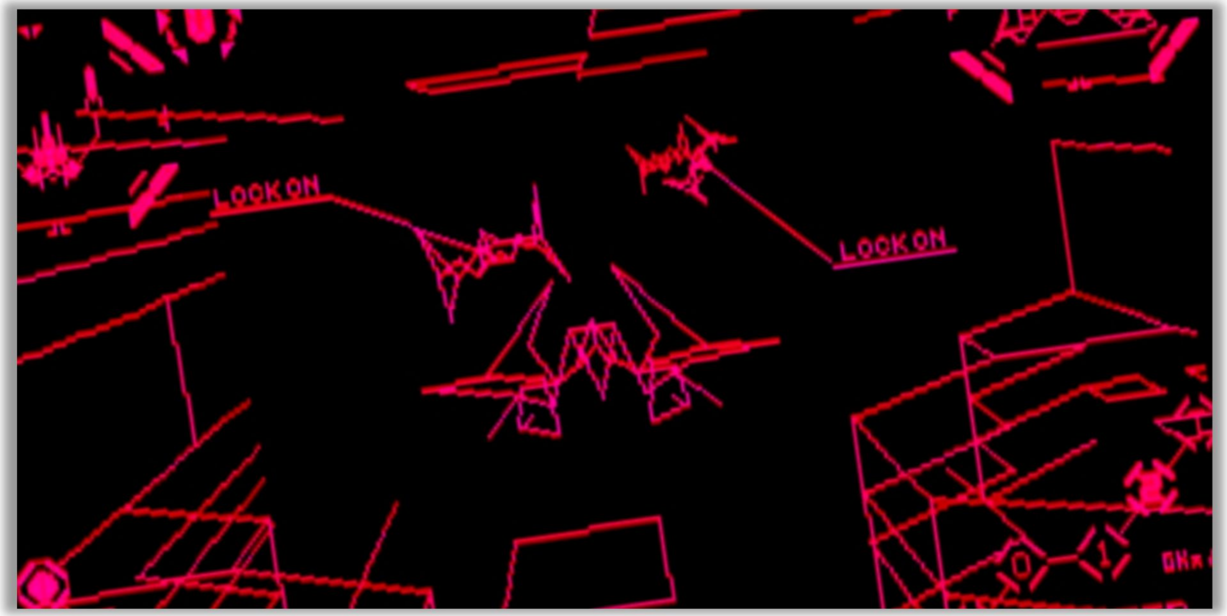
Ivan Sutherland's HMD

- optical see-through AR, including:
  - displays (2x 1" CRTs)
  - rendering
  - head tracking
  - interaction
  - model generation
- computer graphics
- human-computer interaction

I. Sutherland "A head-mounted three-dimensional display", Fall Joint Computer Conference 1968

Nintendo Virtual Boy

- computer graphics & GPUs were not ready yet!

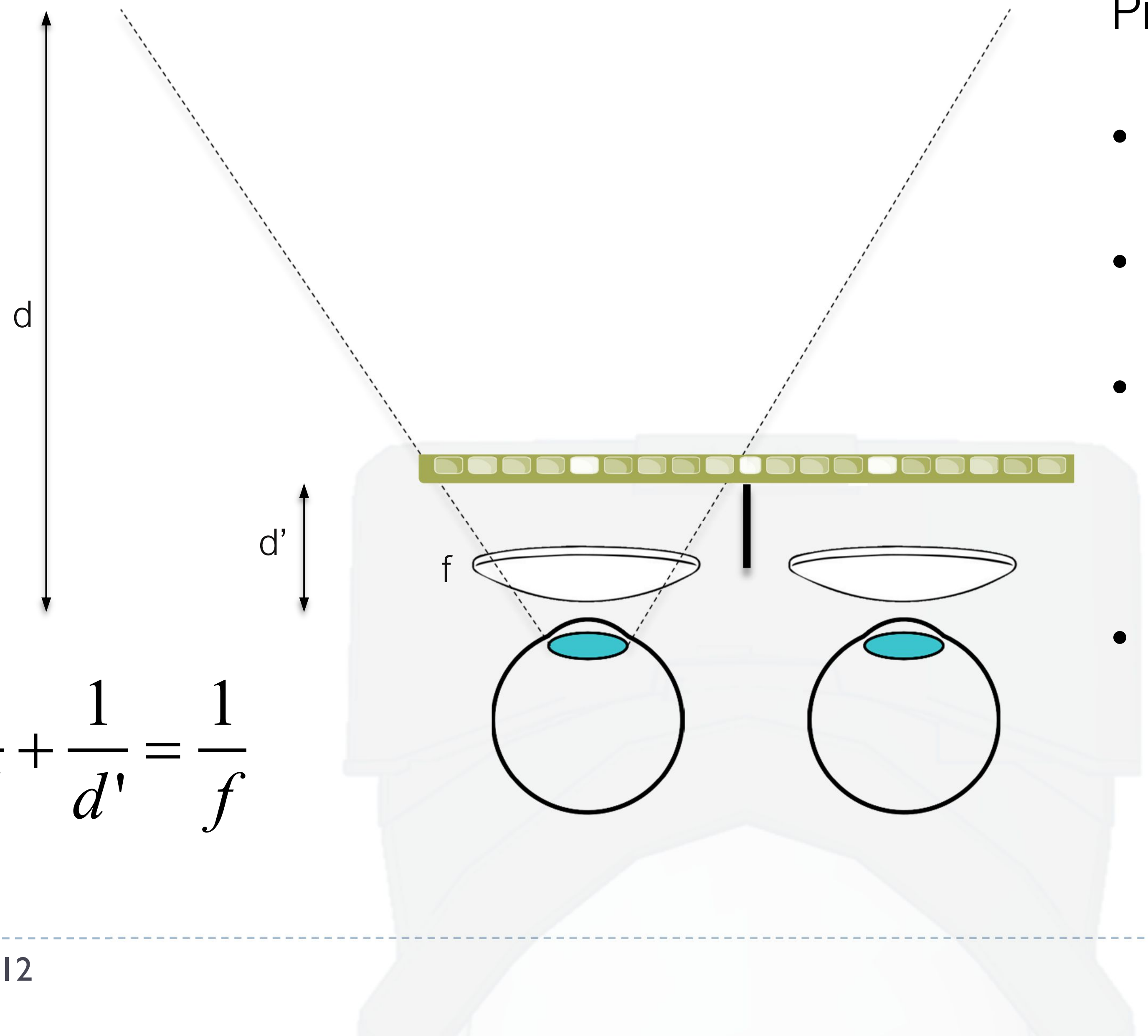


Game: Red Alarm

Where we are now

IFIXIT teardown

Virtual Image

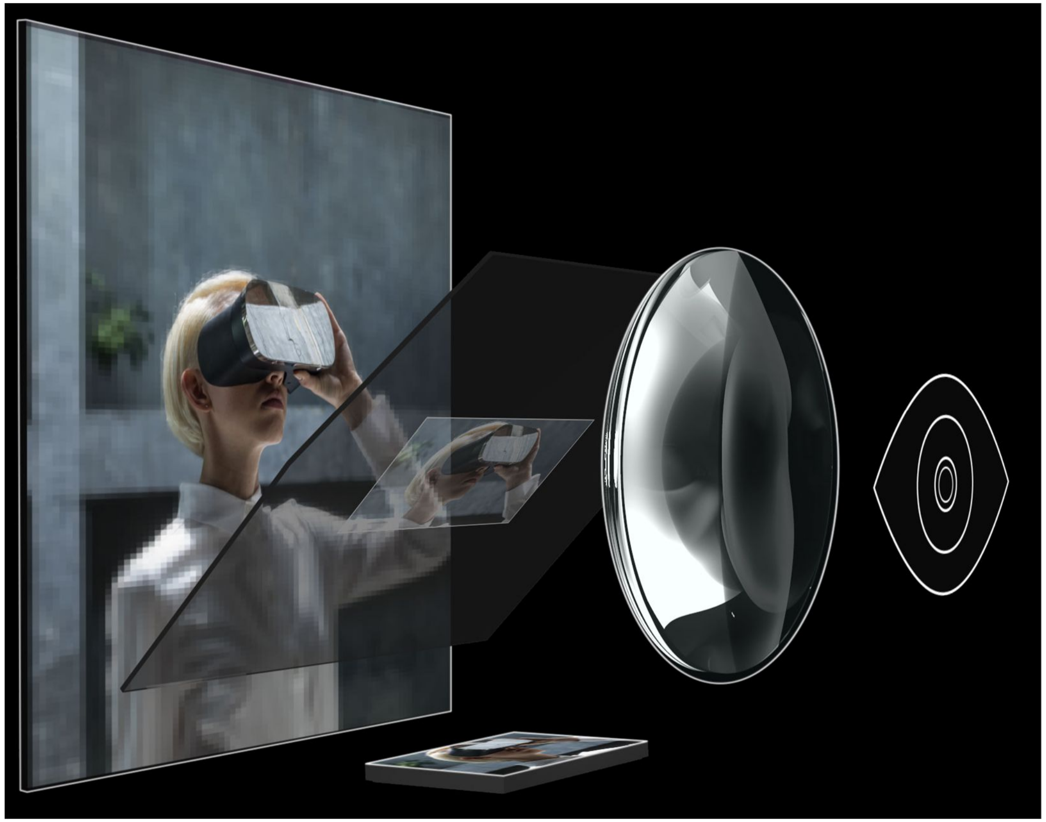


$$\frac{1}{d}+\frac{1}{d'}=\frac{1}{f}$$

Problems:

- fixed focal plane
- no focus cues ☹
- cannot drive accommodation with rendering!
- limited resolution

A dual-resolution display



- High resolution image in the centre, low resolution fills wide field-of-view
- Two displays combined using a beam-splitter
  - Image from: https://varjo.com/bionic-display/

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Virtual and Augmented Reality

Part 2/4 – augmented reality

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The slides used in this lecture are the courtesy of Gordon Wetzstein.
From Virtual Reality course: http://stanford.edu/class/ee267/

Pepper's Ghost 1862

Optical see-through AR / head-up displays

Magic Leap 2

Microsoft Hololens 2

Lumus Maximums

Meta 2
(not the current Meta/Facebook)

Intel Vaunt

Google Glass

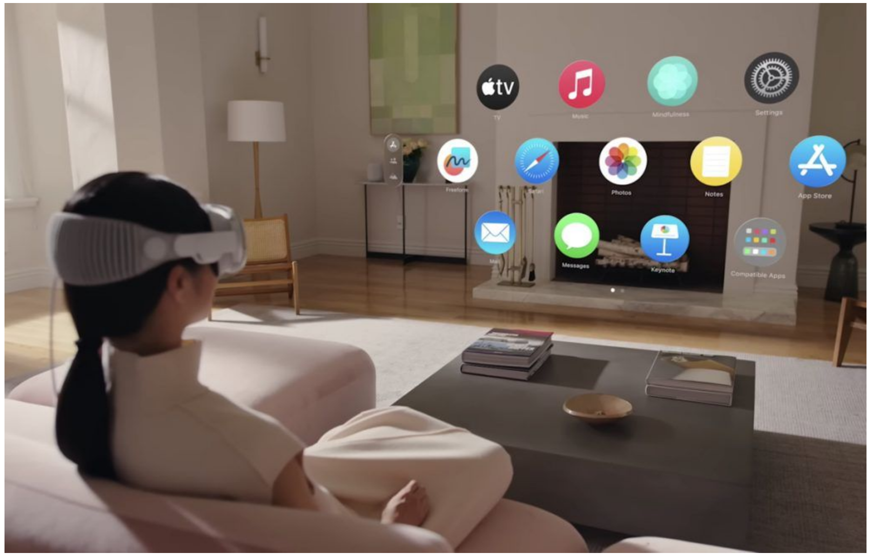
(Some) challenges of optical see-through AR

- Transparency, lack of opacity
  - Display light is mixed with environment light
- Resolution and field-of-view
- Eye-box
  - The volume in which the pupil needs to see the image
- Brightness and contrast
- Blocked vision – forward and periphery (safety)
- Power efficiency
- Size, weight and weight distribution
  - 50 grams are comfortable for long periods
- Social issues, price, vision correction, individual variability…

More resources: https://kguttag.com/

Video pass-through AR

Meta Quest 3



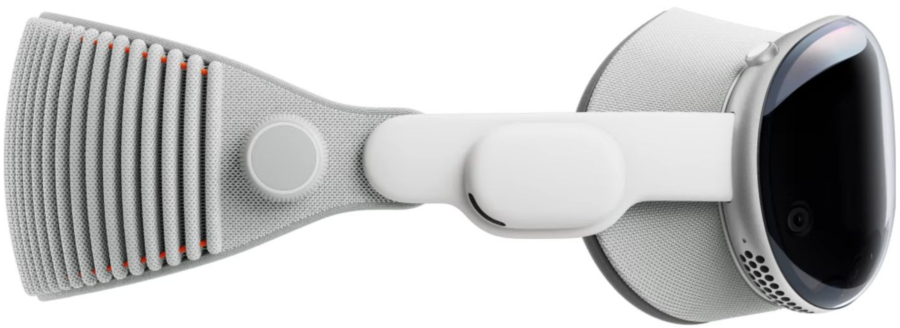
Apple Vision Pro

- Also for smartphones and tablets
- APIs
  - ARCore (by Google, Android/iOS)
  - ARKit (by Apple, iOS)
  - ARToolKit (OpenSource, Multiplatform) - http://www.artoolkitx.org/

Video pass-through AR

Pros:

- Better virtual image quality
- Occlusions are easy
- Simpler, less expensive optics
- Virtual image not affected by ambient light
- AR/VR in one device



Apple Vision Pro

Cons:

- Vergence-accommodation conflict (see the next part)
- Lower brightness, dynamic range and resolution than real-world
- Motion to photon delay
- Real-world images must be warped for the eye position (artifacts)
- Peripheral vision is occluded
  - Or display if affected by ambient light

VR/AR challenges

- Latency (next lecture)
- Tracking
- 3D Image quality and resolution
- Reproduction of depth cues (last lecture)
- Rendering & bandwidth
- Simulation/cyber sickness
- Content creation
  - Game engines
  - Image-Based-Rendering

Simulation sickness

- Conflict between vestibular and visual systems
  - When camera motion inconsistent with head motion
  - Frame of reference (e.g. cockpit) helps
  - Worse with larger FOV
  - Worse with high luminance and flicker

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Virtual and Augmented Reality

Part 3/4 – depth perception

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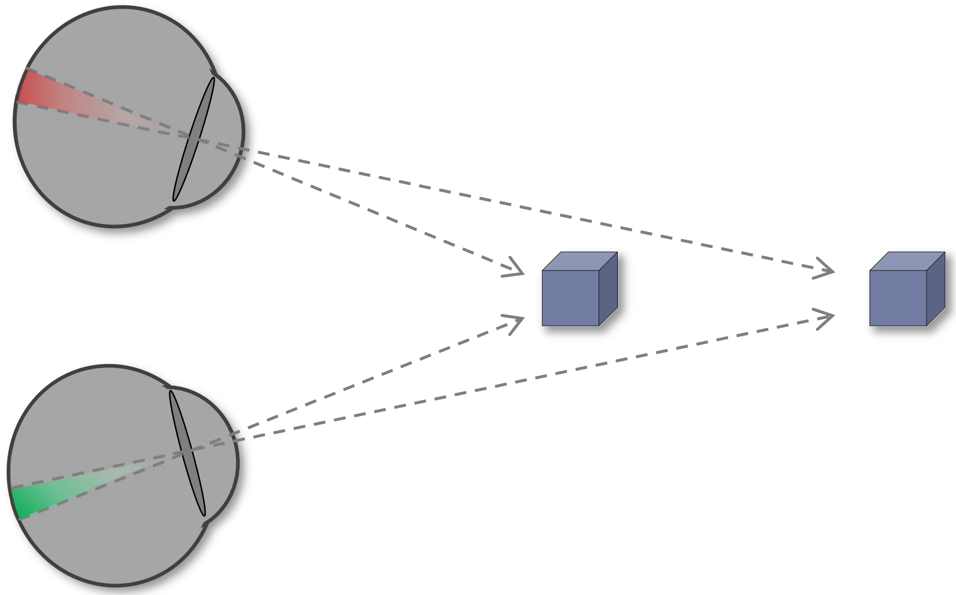
Depth perception

We see depth due to depth cues.

Stereoscopic depth cues:

binocular disparity



The slides in this section are the courtesy of
Piotr Didyk (http://people.mpi-inf.mpg.de/~pdidyk/)

Depth perception

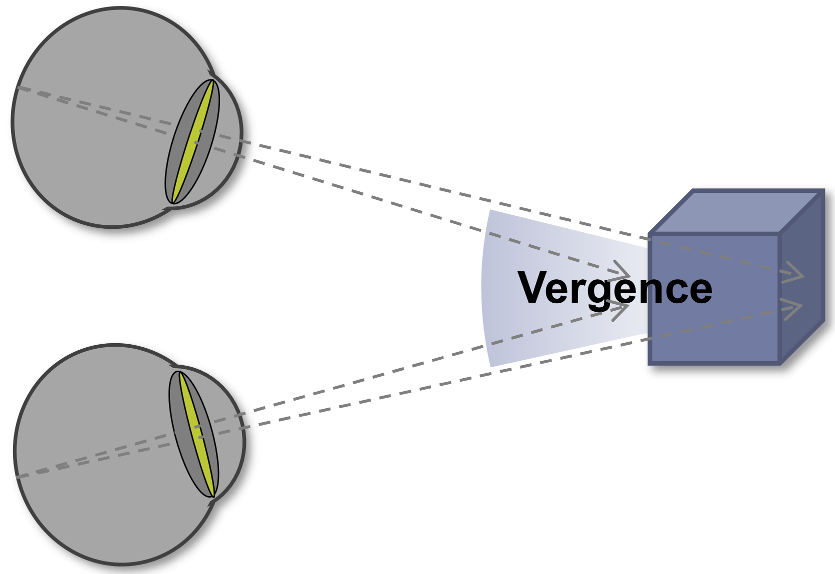
We see depth due to depth cues.

Stereoscopic depth cues:

binocular disparity

Ocular depth cues:

accommodation,   vergence



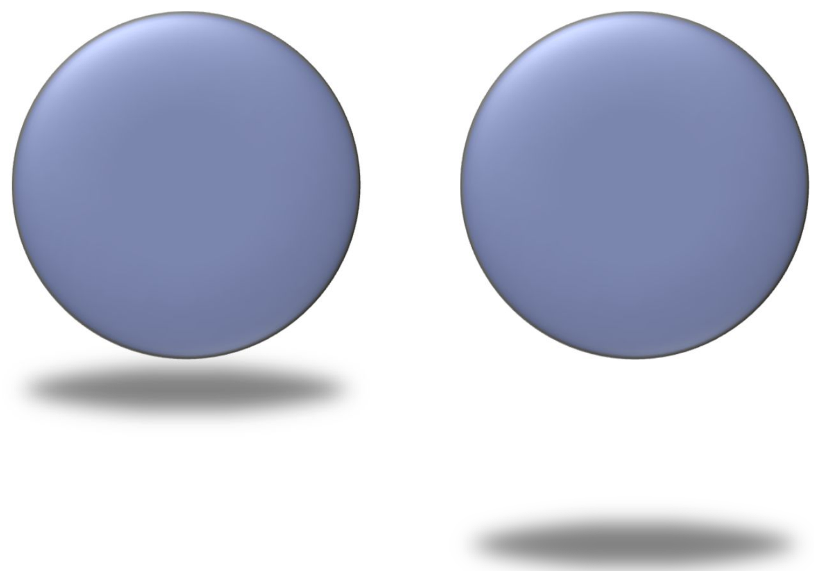
Depth perception

We see depth due to depth cues.

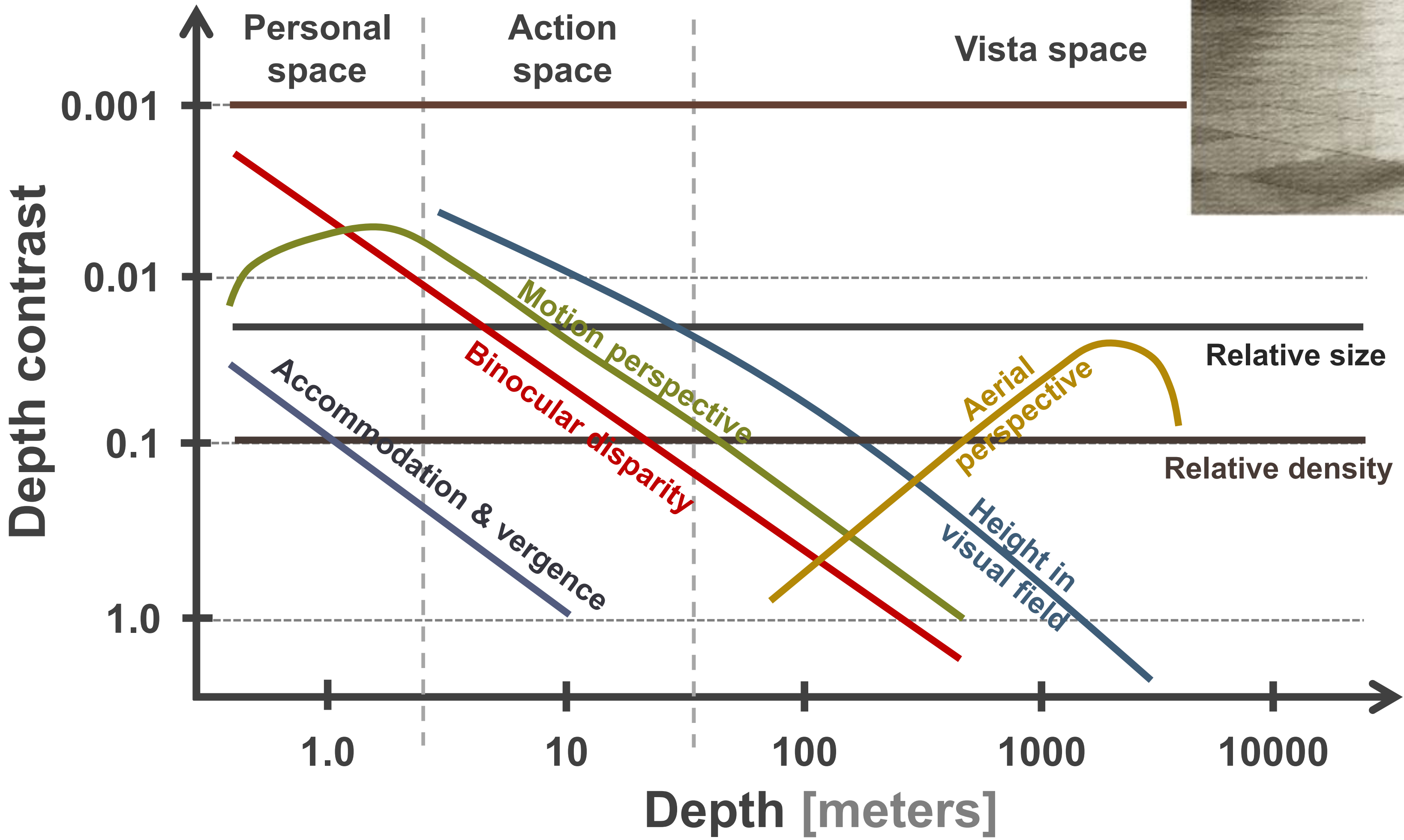
Stereoscopic depth cues:
binocular disparity

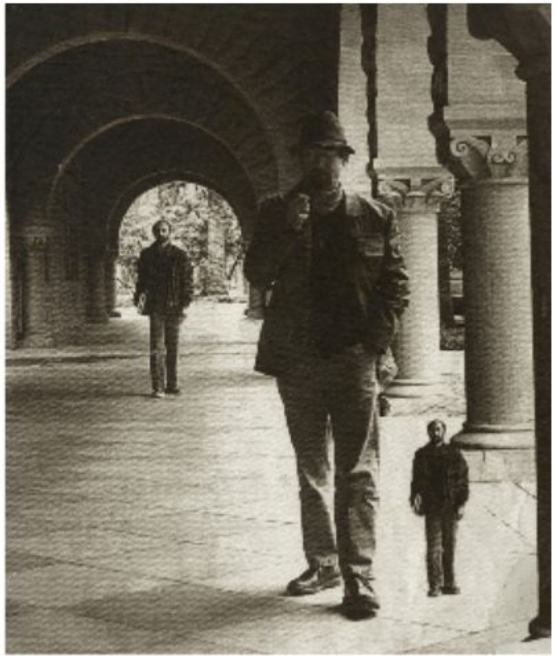
Ocular depth cues:
accommodation, vergence

Pictorial depth cues:
occlusion, size, shadows…



Cues sensitivity





"Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth"
by Cutting and Vishton [1995]

Depth perception

We see depth due to depth cues.

Stereoscopic depth cues:

binocular disparity

Ocular depth cues:

accommodation, vergence

Pictorial depth cues:

occlusion, size, shadows…

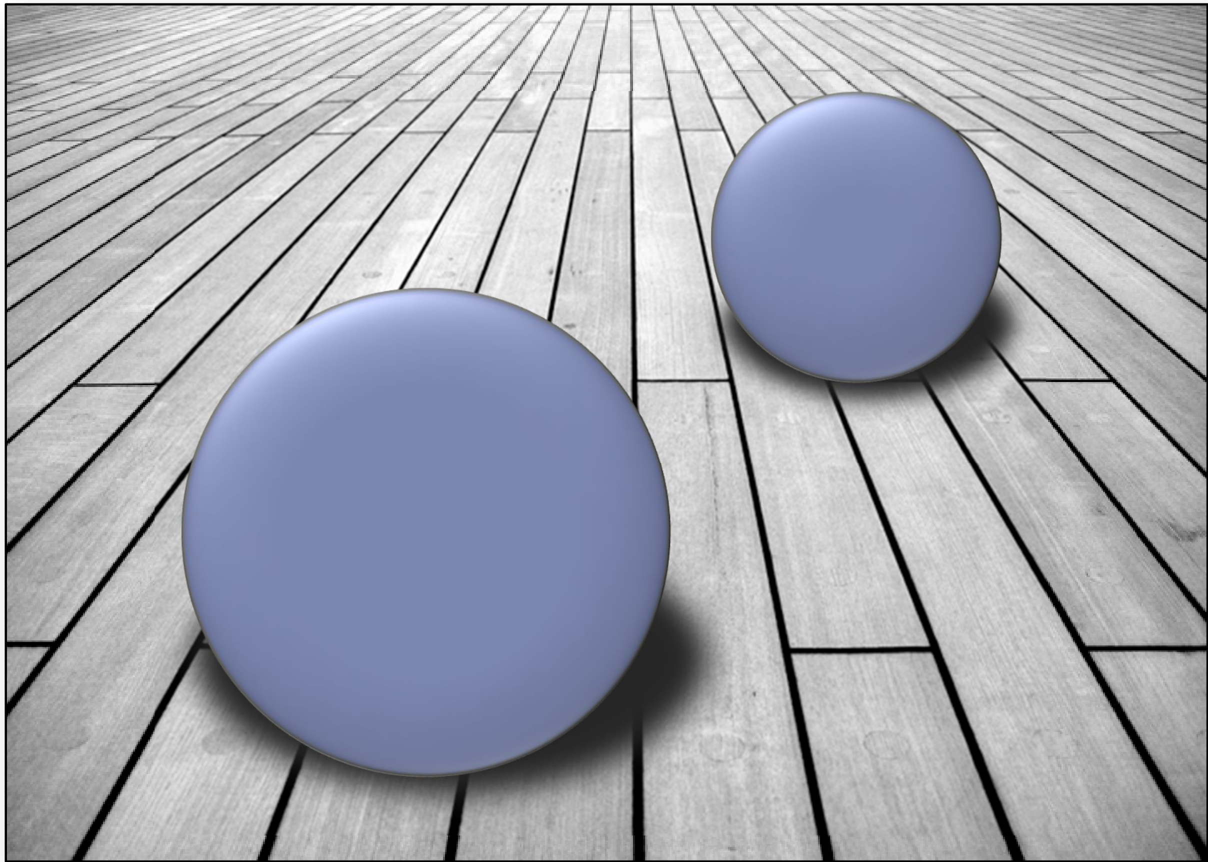
Challenge:
Consistency is required!

Simple conflict example

Present cues:

- Size
- Shadows
- Perspective

- **Occlusion**



Disparity & occlusion conflict

Objects in front

Disparity & occlusion conflict

Depth perception

We see depth due to depth cues.

Stereoscopic depth cues:
binocular disparity

Ocular depth cues:
accommodation, vergence

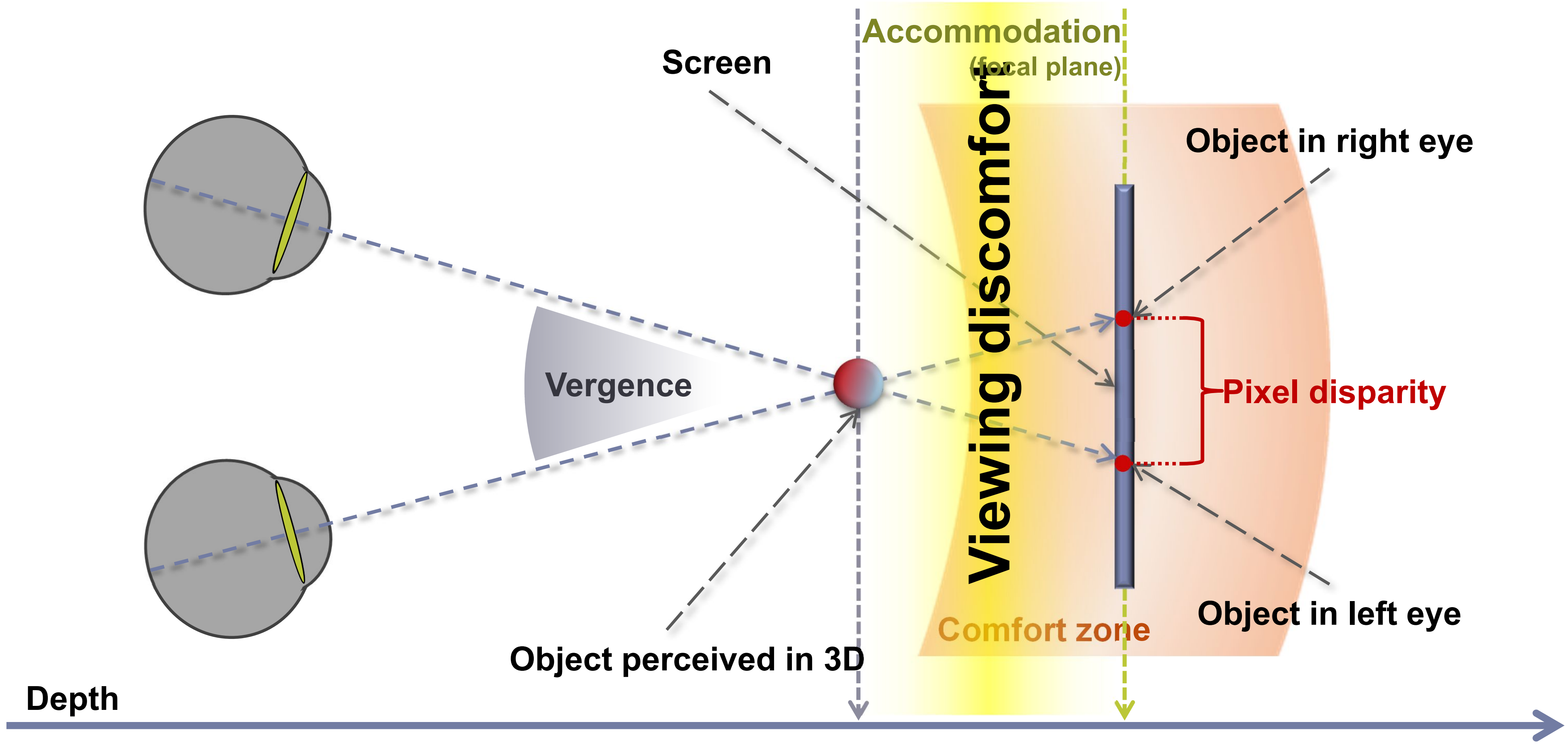
→ **Require 3D space**

We cheat our Visual System!

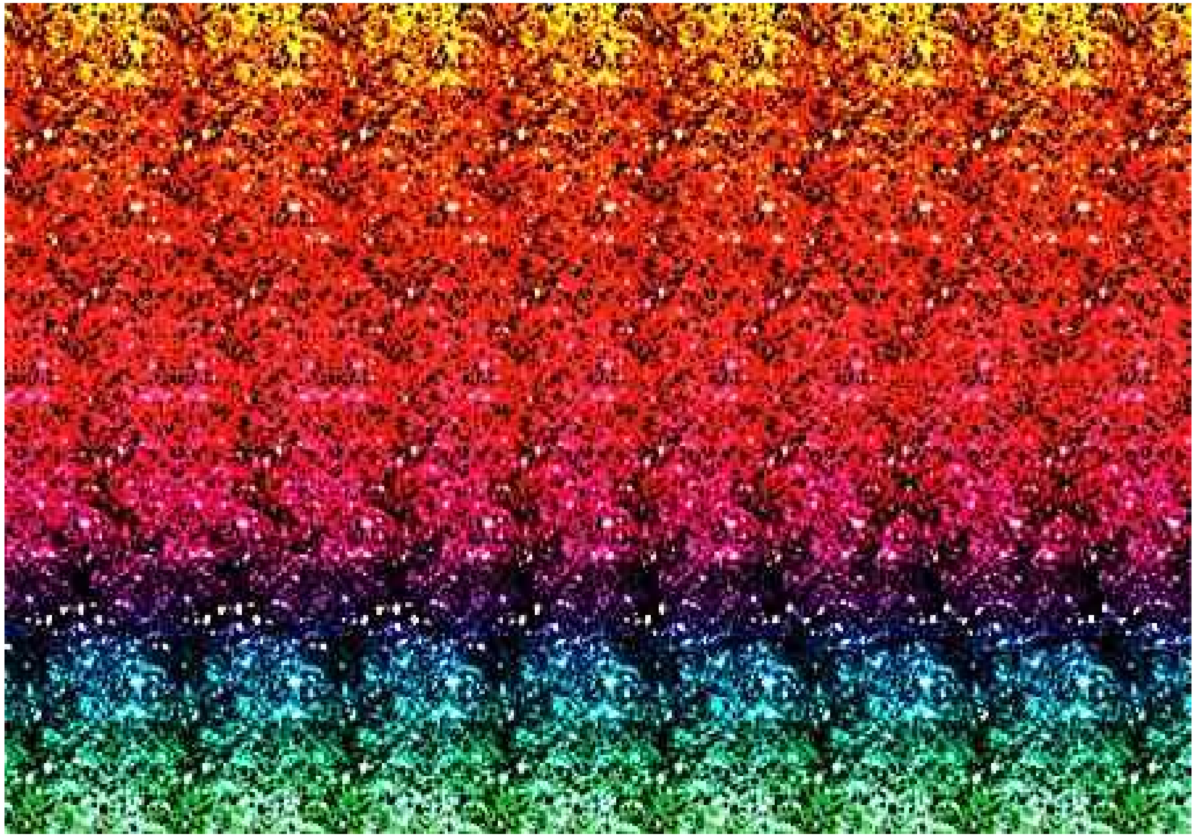
Pictorial depth cues:
occlusion, size, shadows…

→ **Reproducible on a flat displays**

Cheating our HVS

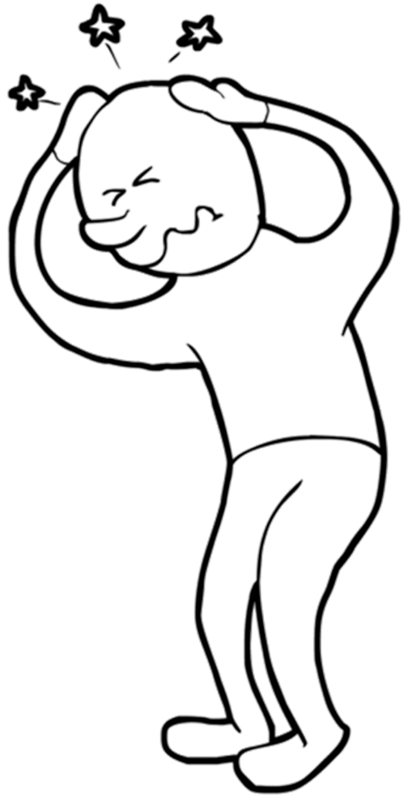


Single Image Random Dot Stereograms



- Fight the vergence vs. accommodation conflict to see the hidden image

Viewing discomfort

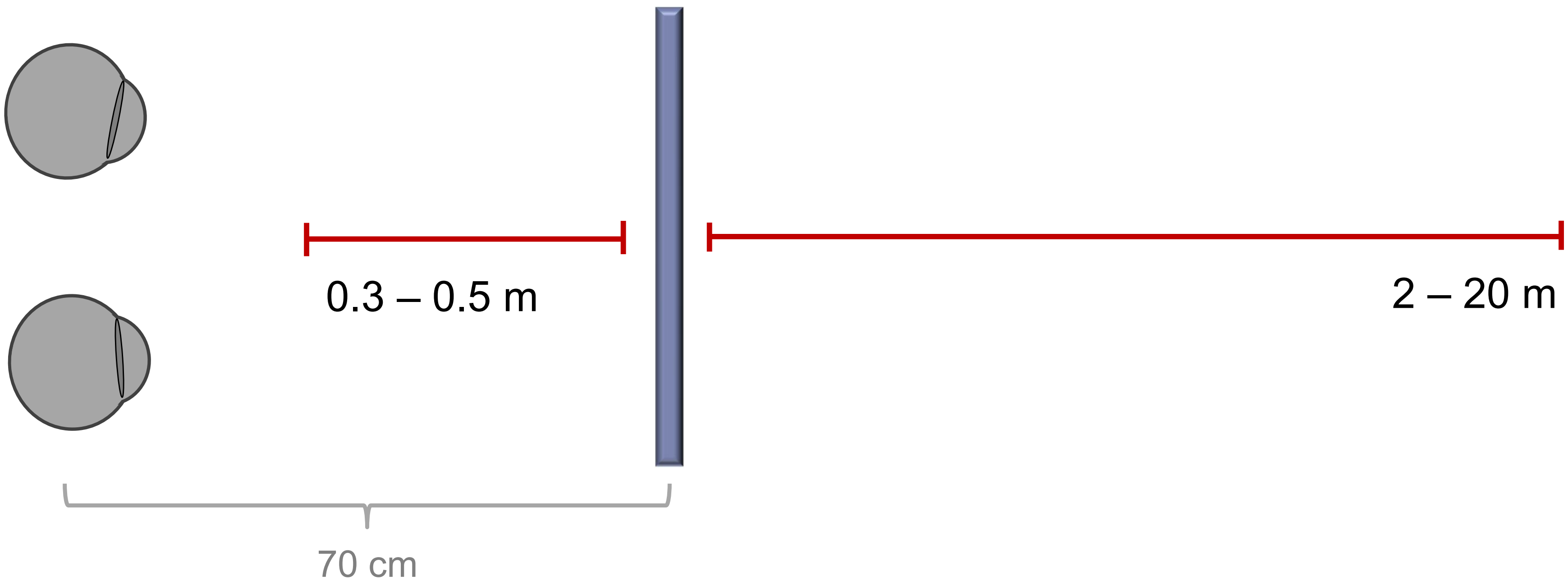


Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Simple scene



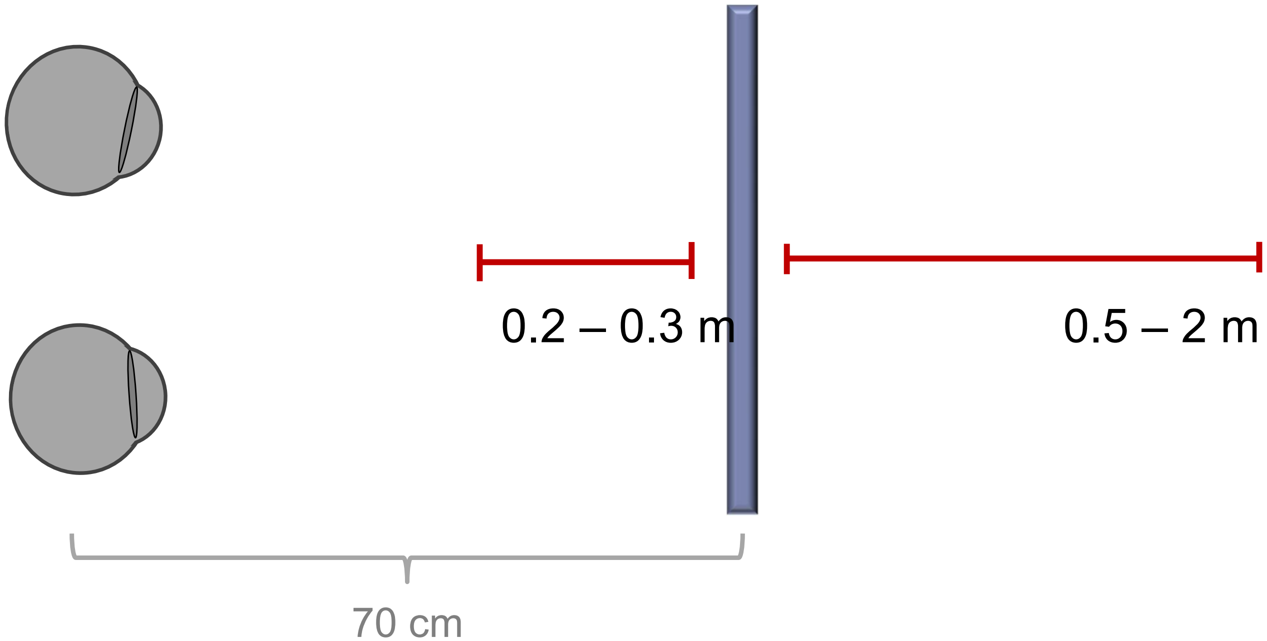
"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Simple scene, user allowed to look away from screen



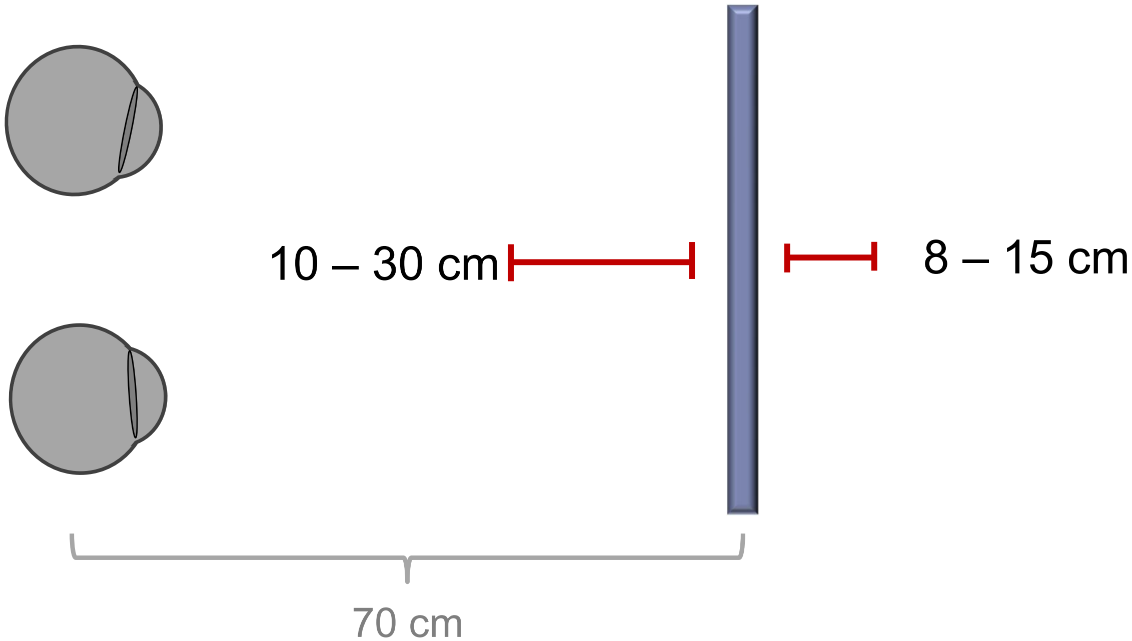
“Controlling Perceived Depth in Stereoscopic Images” by Jones et al. 2001

Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Difficult scene



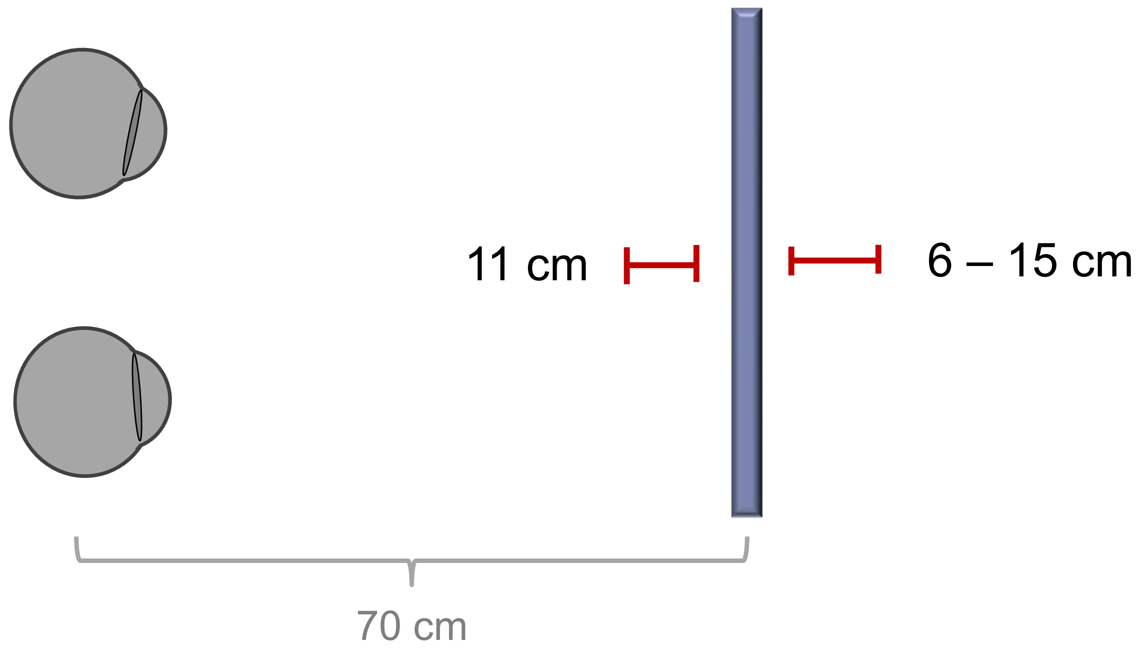
"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Difficult scene, user allowed to look away from screen



"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

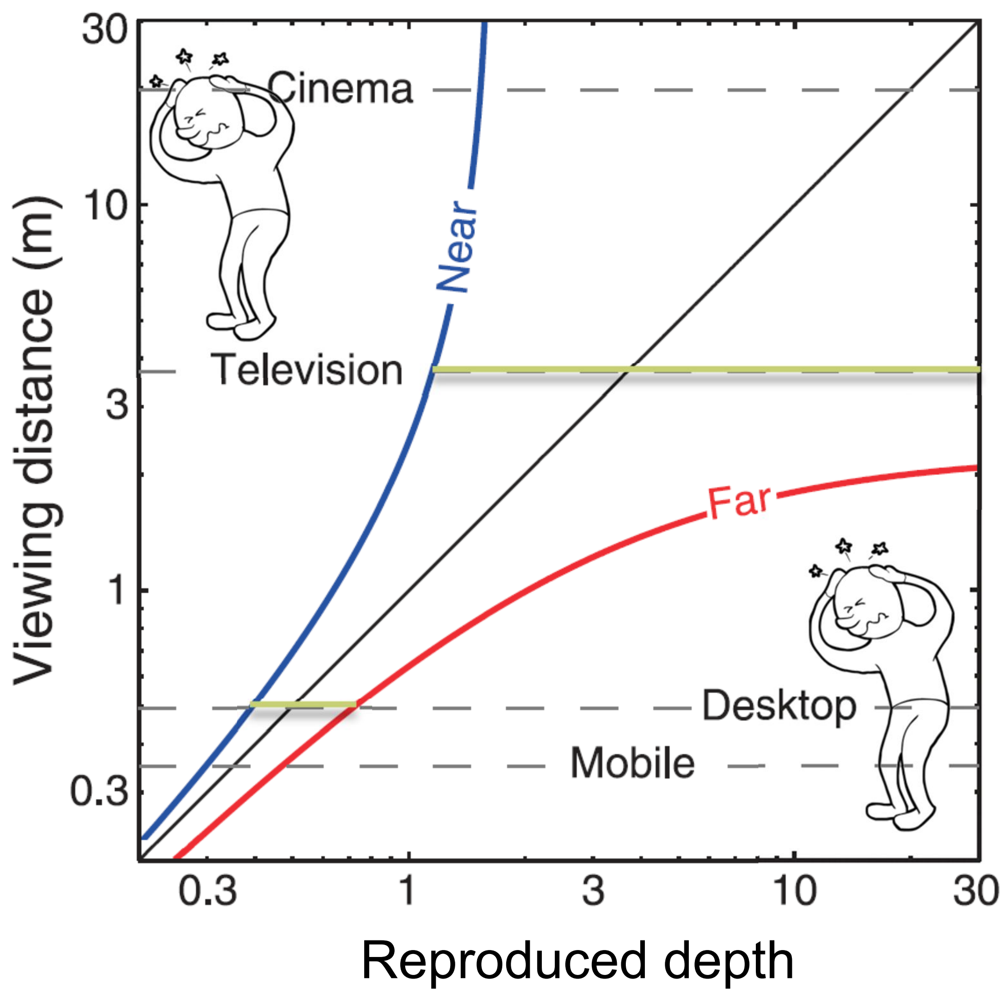
Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition
- Screen distance

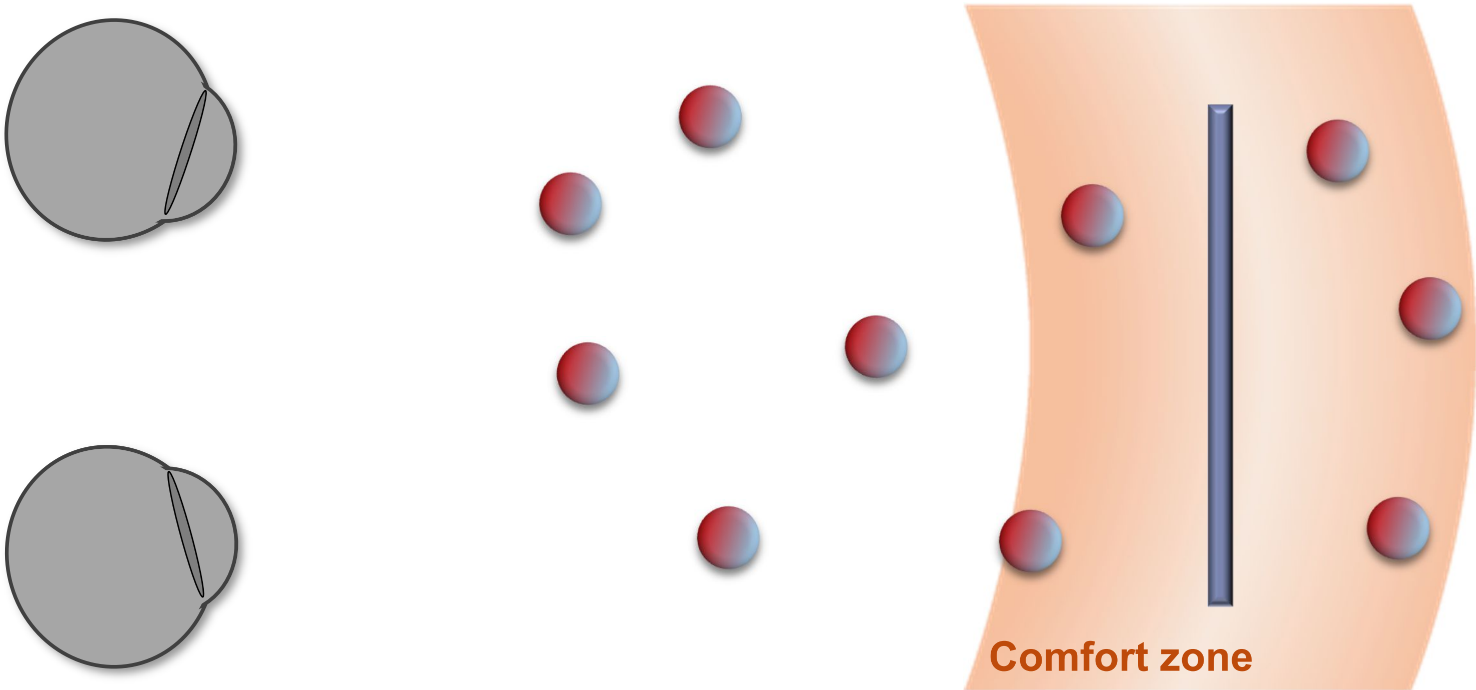
Other factors:

- Distance between eyes
- Depth of field
- Temporal coherence



“The zone of comfort: Predicting visual discomfort with stereo displays” by Shibata et al. 2011

Depth manipulation



Viewing discomfort $\xrightarrow{\text{Scene manipulation}}$ **Viewing comfort**

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Virtual and Augmented Reality
Part 4/4 – stereo rendering

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Put on Your 3D Glasses Now!

The slides used in this section are the courtesy of Gordon Wetzstein.
From Virtual Reality course: http://stanford.edu/class/ee267/

pintrest.com

Anaglyph Stereo - Monochrome

- render L & R images, convert to grayscale
- merge into red-cyan anaglyph by assigning I(r)=L, I(g,b)=R (I is anaglyph)


from movie “Bick Buck Bunny”

Anaglyph Stereo – Full Color

- render L & R images, do not convert to grayscale
- merge into red-cyan anaglyph by assigning I(r)=L(r), I(g,b)=R(g,b) (I is anaglyph)


from movie "Bick Buck Bunny"

Open Source Movie: Big Buck Bunny

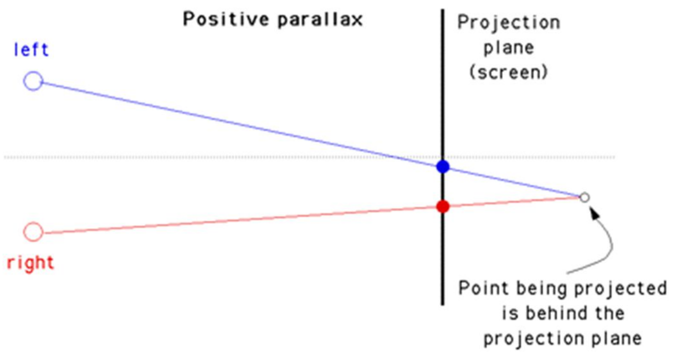
Rendered with Blender (Open Source 3D Modeling Program)

http://bbb3d.renderfarming.net/download.html

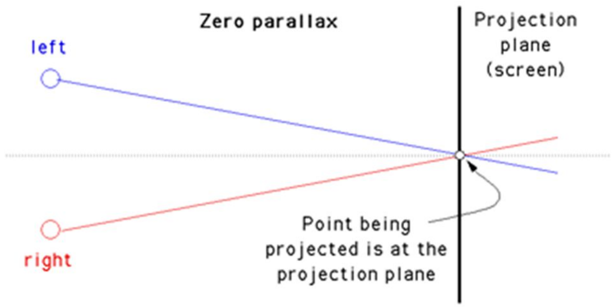
http://paulbourke.net/stereographics/stereorender/

Parallax

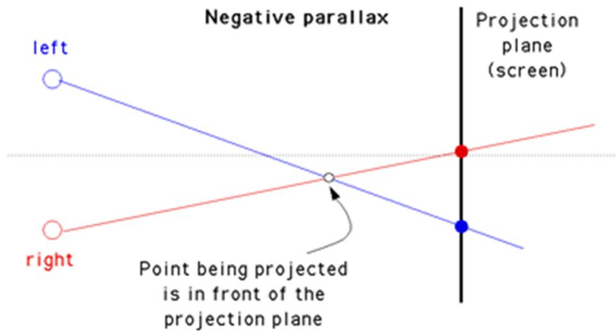
- Parallax is the relative distance of a 3D point projected into the 2 stereo images



case 1



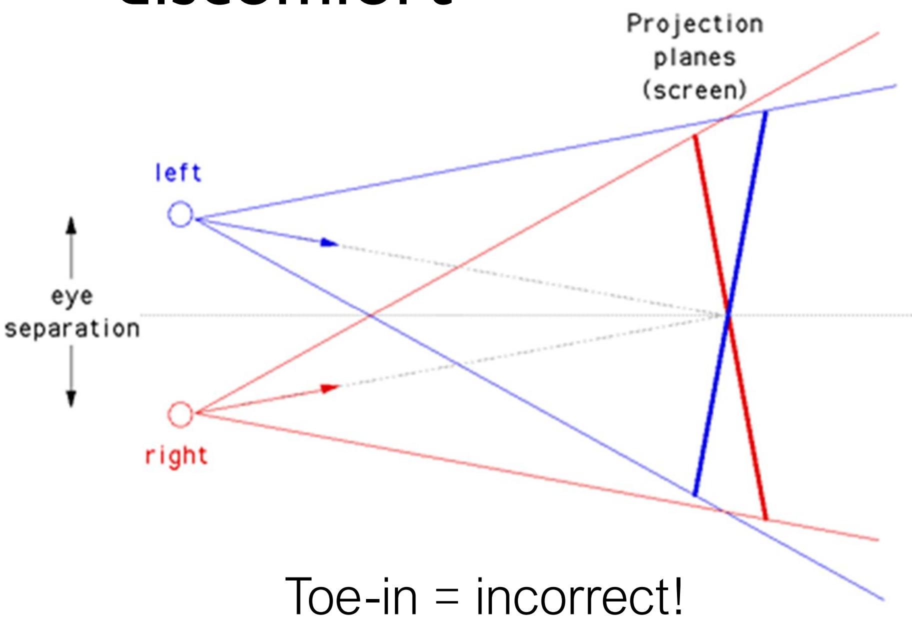
case 2



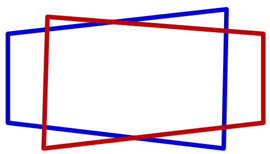
case 3

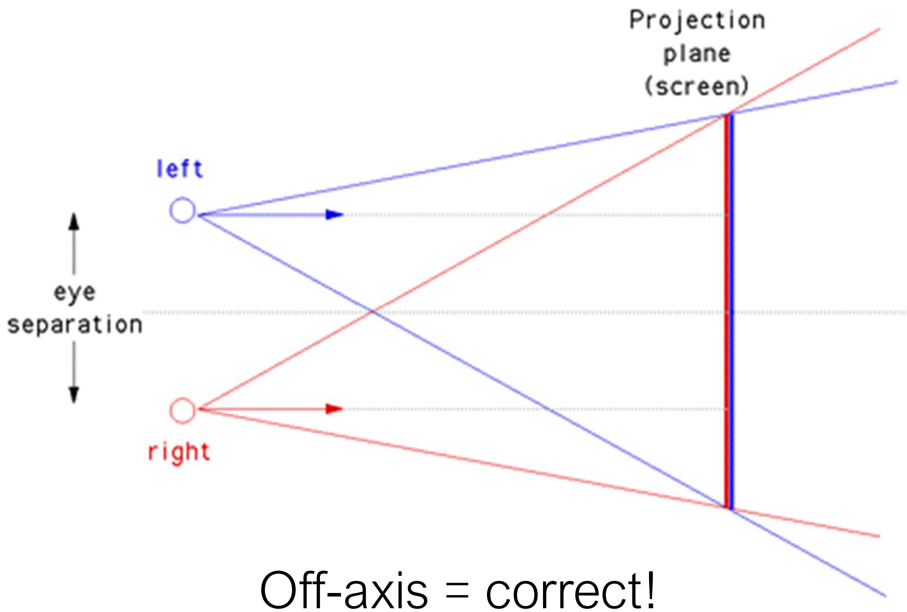
Parallax

- visual system only uses horizontal parallax, no vertical parallax!
- naïve toe-in method creates vertical parallax and visual discomfort

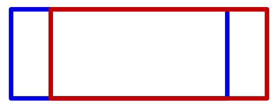


Toe-in = incorrect!

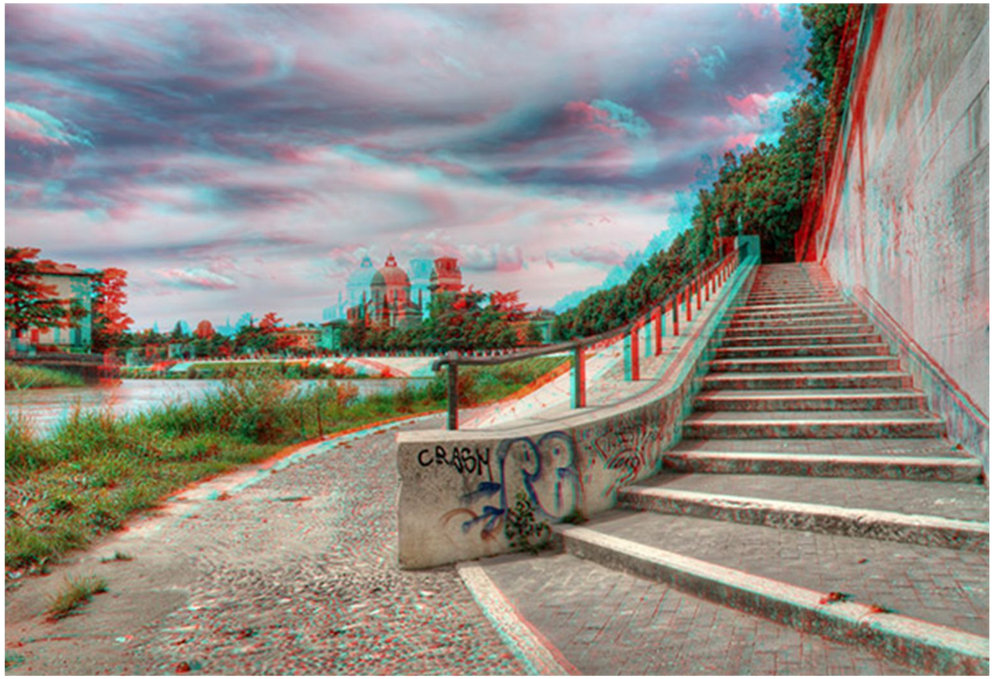




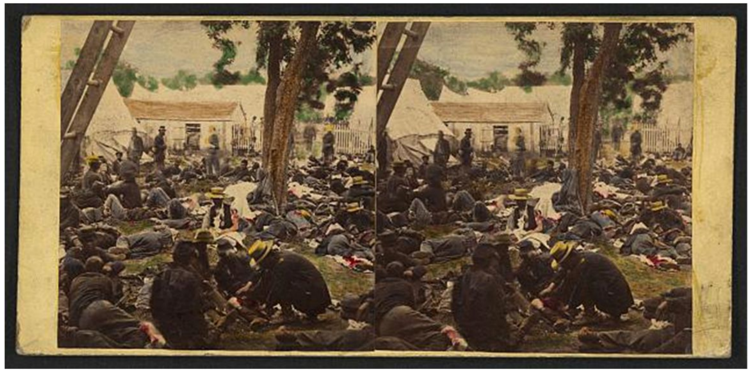
Off-axis = correct!



Parallax – well done



Parallax – well done



1862
“Tending wounded Union soldiers at Savage's Station, Virginia, during the Peninsular Campaign”,
Library of Congress Prints and Photographs Division

Parallax – not well done (vertical parallax = unnatural)

References

- LaValle "Virtual Reality", Cambridge University Press, 2016
  - http://vr.cs.uiuc.edu/
- Virtual Reality course from the Stanford Computational Imaging group
  - http://stanford.edu/class/ee267/
- KGOnTech blog
  - https://kguttag.com/

- The selected slides used in this lecture are the courtesy of Gordon Wetzstein (Virtual Reality course: http://stanford.edu/class/ee267/)