The human visual system and a VR/AR head-mounted display

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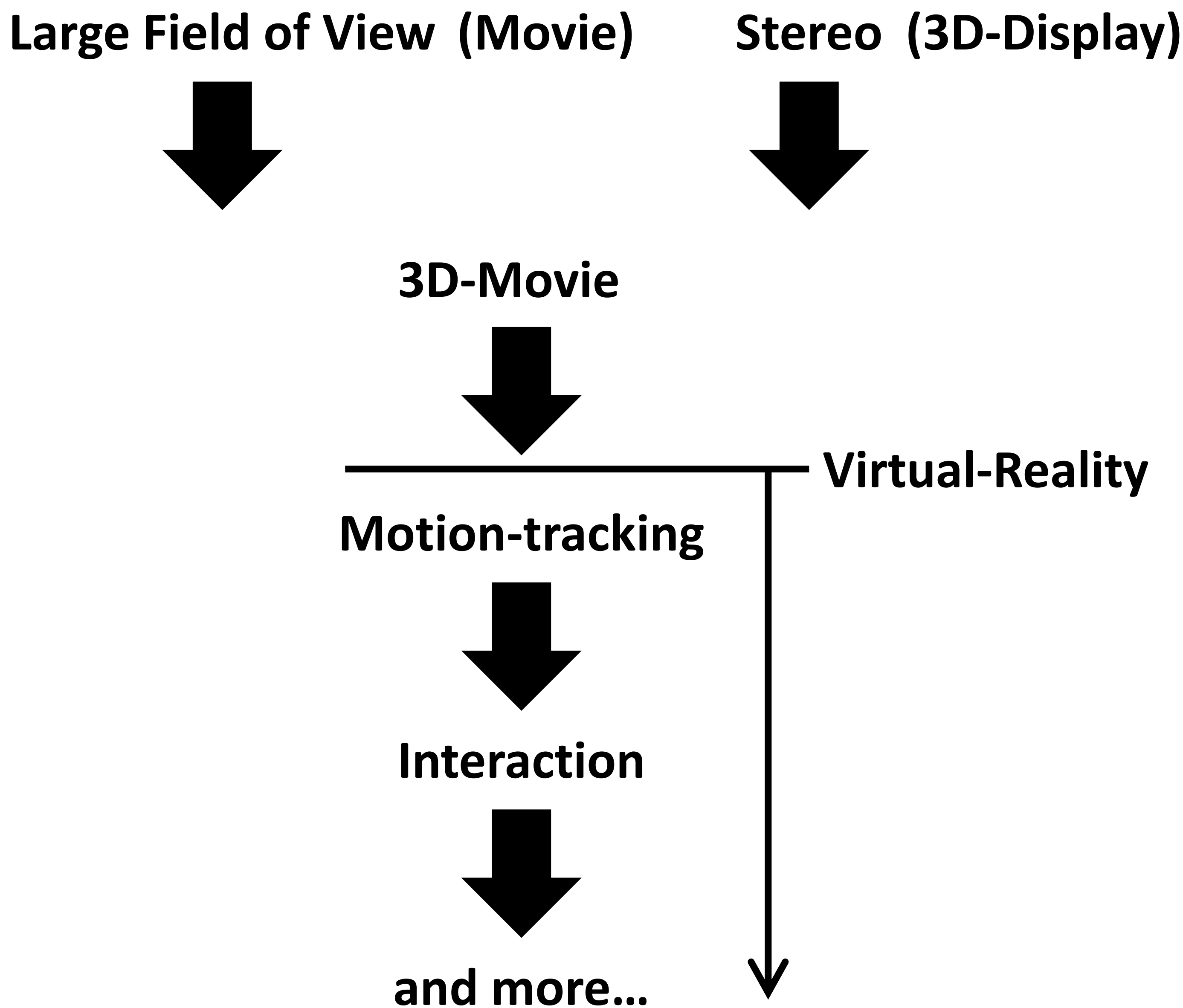
From a Display to a VR-device



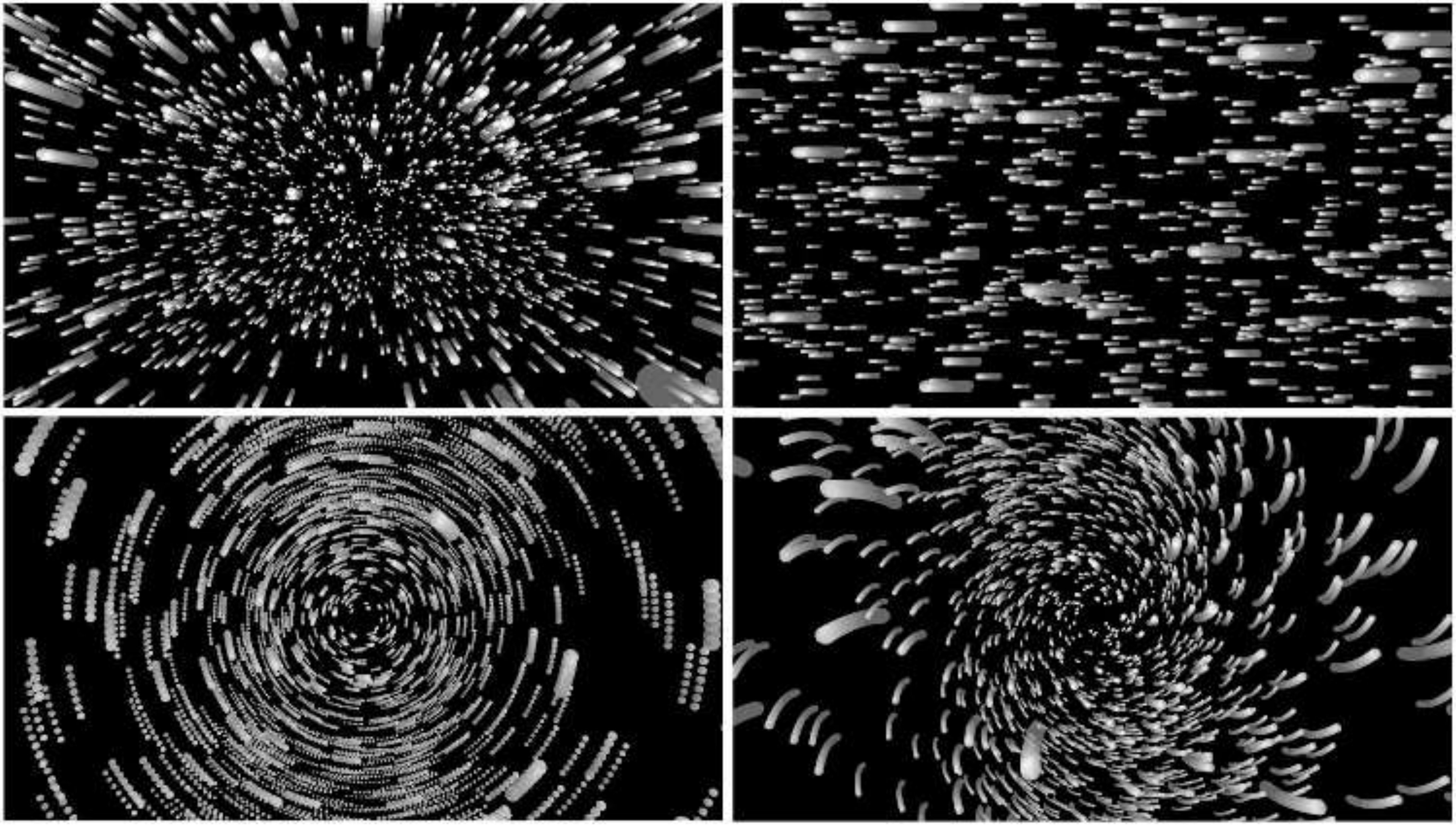
Large field of view

A large field of view is a critical factor for perceiving “***vection***” (visually-evoked-action) from a visual stimulus.

Palmisano et al. (2015)

Väljamäe et al. (2008)

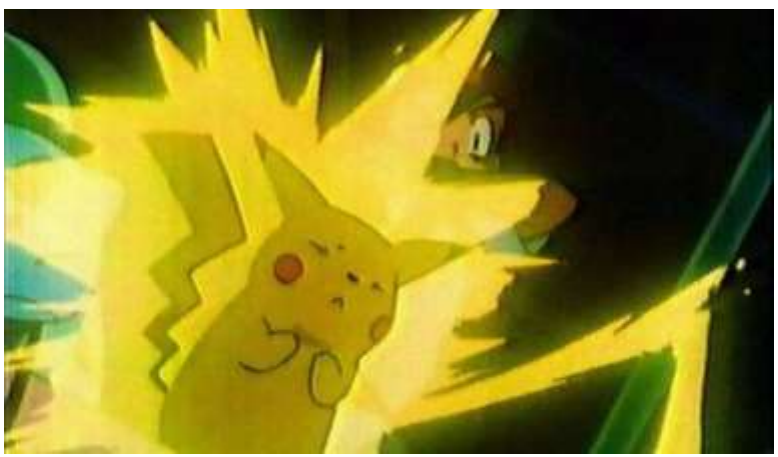
Large field of view



Palmisano, Allison, Schira, Barry (2015)
https://doi.org/10.3389/fpsyg.2015.00193

Photosensitive epilepsy

Visual information from VR devices occupies wide field of view. It means side effects of the visual information can be also bigger.
Epileptic seizures can be induced by image flickers. It is suggested to avoid an image flicker between 2 Hz and 55 Hz should for the seizures (in the section 508 of the Rehabilitation Act in the USA, https://www.section508.gov/content/quick-reference-guide, see also Walter, Dovey, & Shipton, 1946; Epilepsy action, 2010).



https://en.wikipedia.org/wiki/Denn%C5%8D_Senshi_Porygon
http://gizmodo.com/a-grand-jury-just-called-tweeting-an-animated-gif-assau-1793477149

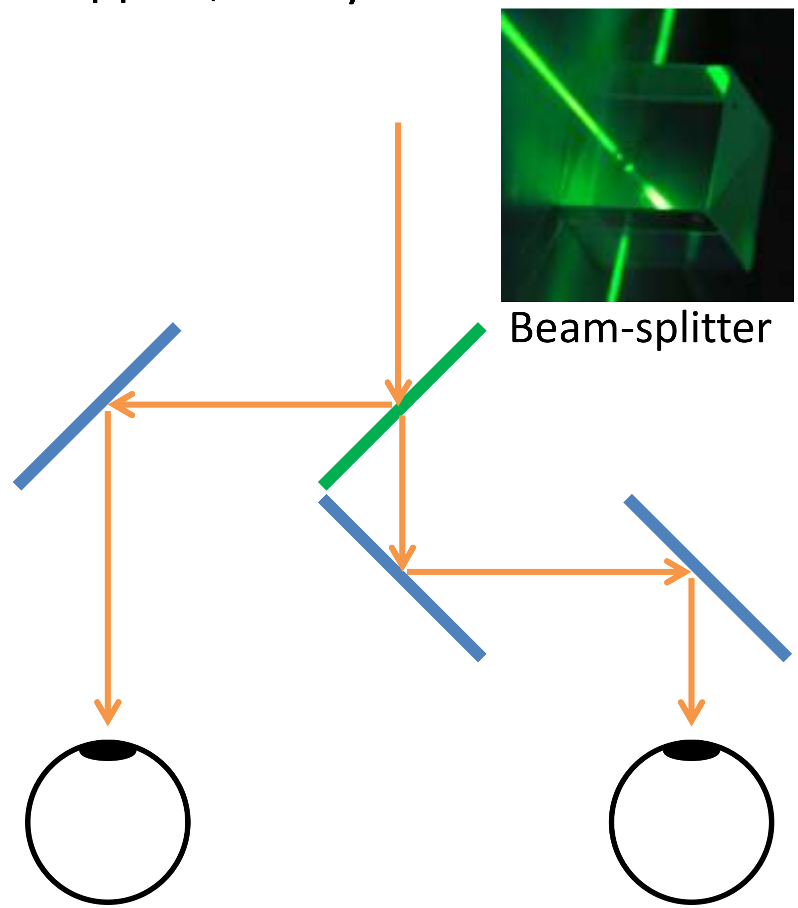
Stereo (binocular-disparity)

Humans can perceive depth from binocular-disparity, which is a small difference between a stereo pair of retinal images.
Note that it is the best studied depth cue of the human visual system (Howard & Rogers, 2012).

Stereo (binocular-disparity)

3~14% of people are stereo-blind/-deficient (Gaudia et al., 2014).

Humans can have stereo-like experience of a scene using a synopter (Wijntjes et al., 2016; Koenderink, van Doorn, & Kappers, 1994).



(Moritz von Rohr, patented by CarlZeiss, 1907)

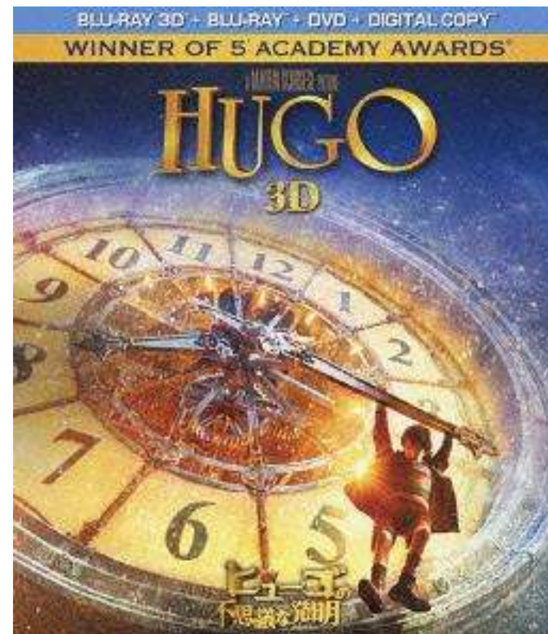
http://binnenland.eenvandaag.nl/radio-items/60101/ik_neem_je_mee_synopter_in_het_rijksmuseum

https://physics.aps.org/story/v13/st21

Stereo (binocular-disparity)

- Bruce Bridgeman (1944–2016)
  Professor at UCSC in Cognitive Psychology
  Strabismus diagnosed at 8yo
  Stereo-blind until 2012
  Watching a 3D movie “Hugo” and gaining stereo vision (2012)

Bridgeman was "euphoric.“



https://edition.cnn.com/2013/06/15/health/stereo-vision-recovery/index.html
https://www.newyorker.com/magazine/2006/06/19/stereo-sue

Stereo (binocular-disparity)

Strabismus is developed before 6 years old of life (Hollwich, 1983/1986).
60% of cases before 2yo and the other 40% before 6yo.

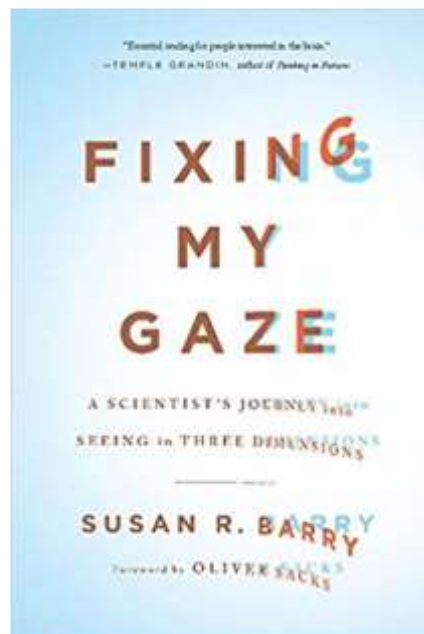
At least, there is one case report (Tsukuda & Murai, 1988). A 4yo child developed strabismus (*acute onset esotropia*) after watching a 3D movie (probably, 15 min long cartoon animation using anaglyph).

(This is just *a case report* and no other case is known.)

Stereo (binocular-disparity)

- Susan R. Barry (a.k.a. Stereo Sue)
  Professor at Mount Holyoke College in Neurobiology
  Strabismus found at a few month old by her parents
  Corrective operations at 2, 3, and 7yo
  Having some vision therapies and gaining stereo vision at 48yo

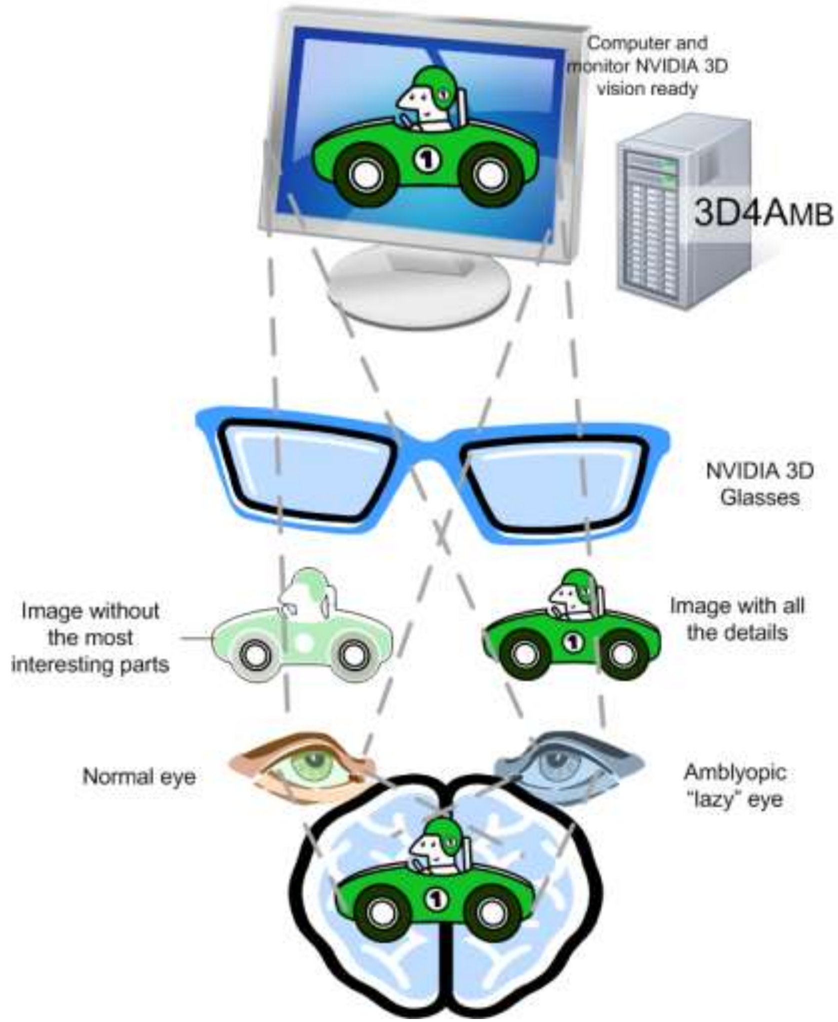
"absolutely delightful,"



https://edition.cnn.com/2013/06/15/health/stereo-vision-recovery/index.html
https://www.newyorker.com/magazine/2006/06/19/stereo-sue

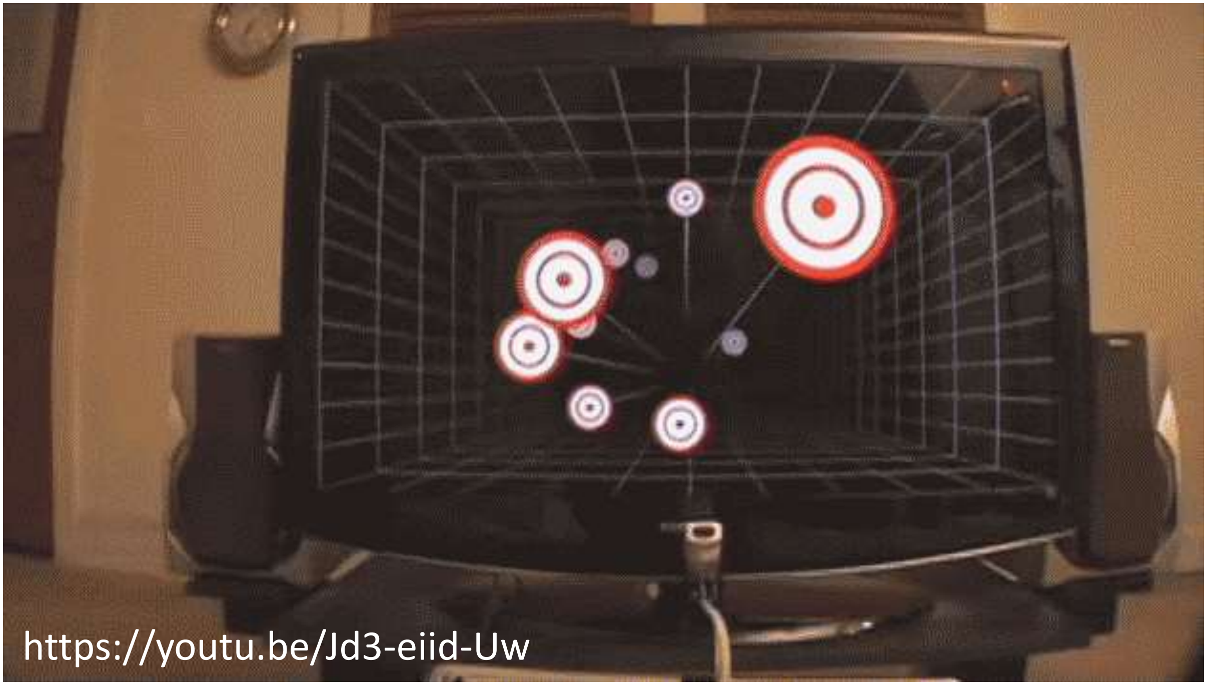
Stereo (binocular-disparity)

Treatment for Amblyopia (see Vivid Vision; Foss, 2017; Gargantini et al., 2017)



http://3d4amb.unibg.it/principles.html

Motion-parallax and Head-tracking



We perceive 3D if an image on a display changes synchronously with our head motion. Therefore, VR should come with head-tracking:

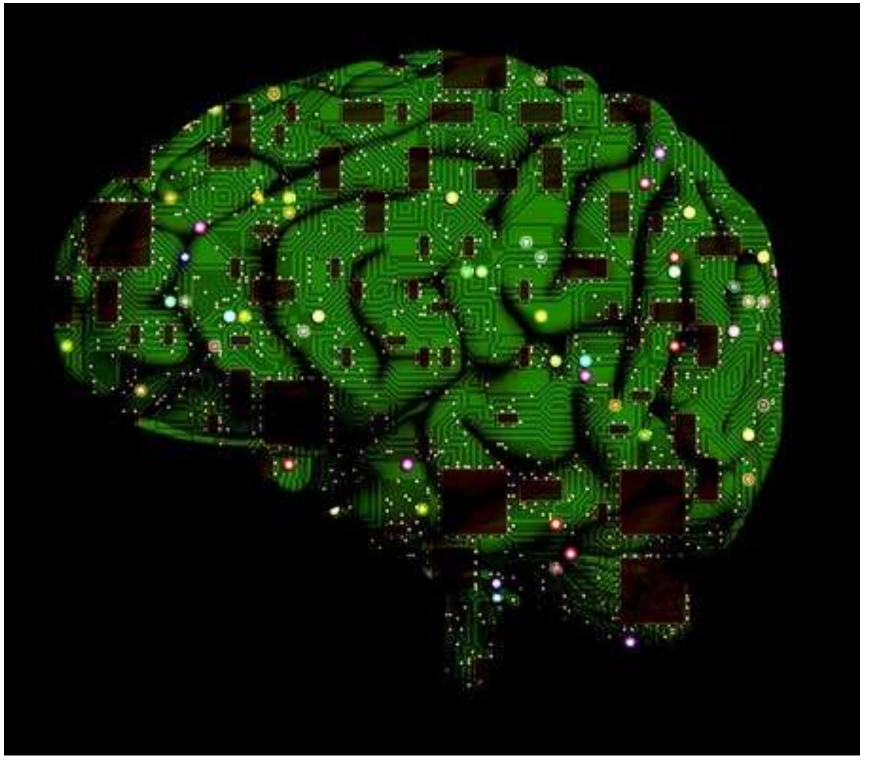
(1) Rotation only (e.g. Google cardboard)

(2) Rotation + Translation (e.g. Oculus and Vive)

If the image does not change…

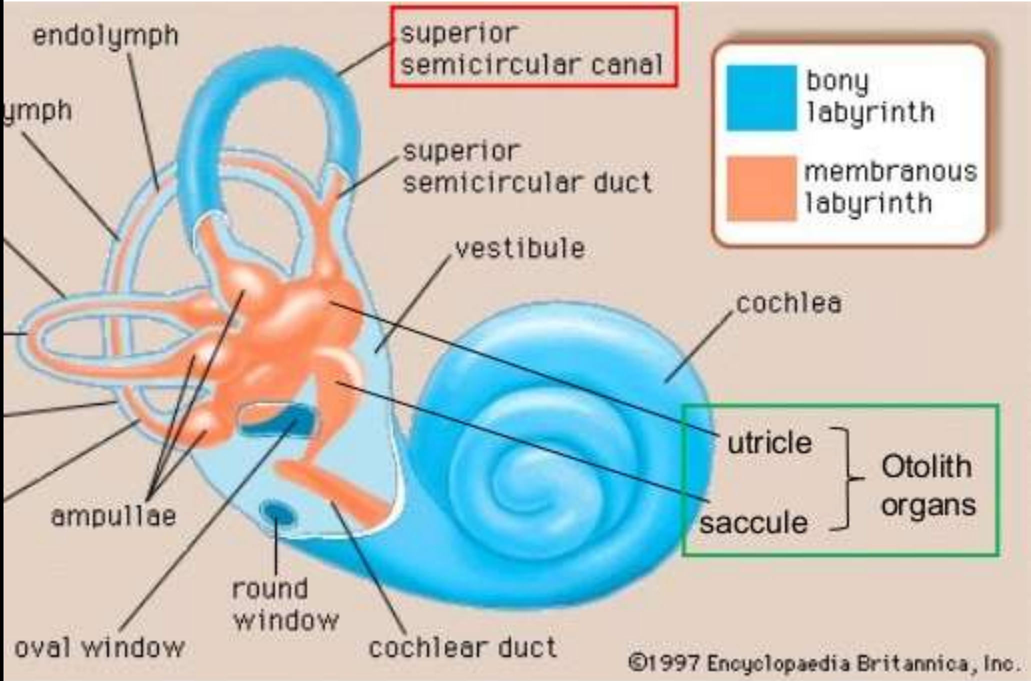
Other types of sensory information for VR

- Vestibular information
- Somatosensory information (including tactile information)
- Auditory information
- Haptic information
- Olfactory information
- Gustatory information



Vestibular information

The vestibular system (semicircular-canals, utricle, saccule) is for perception of body/head orientation and motion. In short, it is an accelerometer for rotational (3df) and linear (3df) motions. It cannot detect position or speed but acceleration.



Vestibular information

The vestibular system is controlled in scientific experiments often by (1) using the gravity by changing a head/body orientation or (2) physically moving the body (e.g. a tumbling room in CVR at York Univ.).

http://yfile-archive.news.yorku.ca/2004/04/29/bbc-arrives-at-york-to-highlight-vision-research/

https://jp.pinterest.com/pin/368028600784894849/

Vestibular information

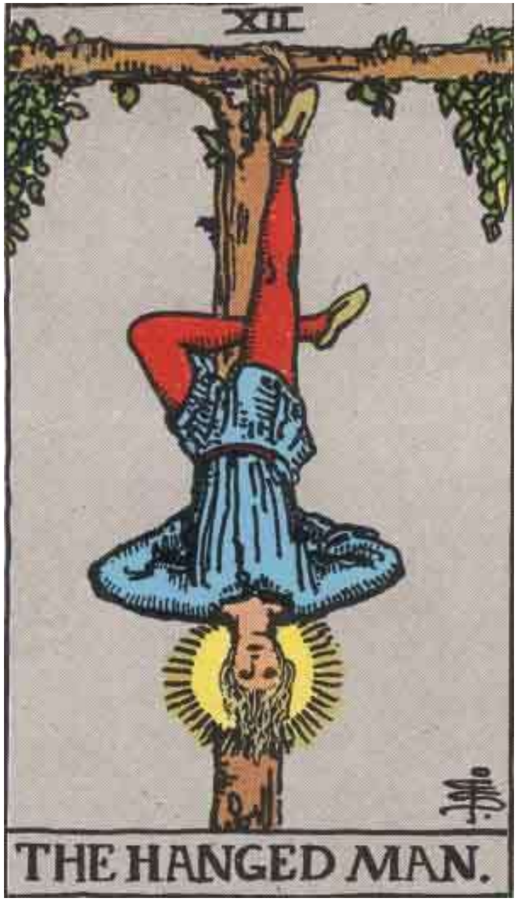
The vestibular system can be stimulated artificially using Galvanic-Vestibular-Stimulation and it causes reflexive actions of a body. However, mechanism of this phenomenon and a relation between the stimulation and the response of the system is still unclear (Fitzpatrick & Day, 2006).

https://youtu.be/oefVaHDo5xg

https://youtu.be/yZ_G_zbObWU

Somatosensory information

Somatosensory information is about changes of body parts (inside/outside). For VR, mechanical movements of a body and physical interaction of the body with a 3D scene (e.g. air pressure).



Somatosensory information

Interface for the human somatosensory system.

Visual, Vestibular, and Somatosensory information

Drop1: Vestibular = 0G, Somatosensory = motion↓ (wind)

Drop2: Vestibular = 1G↓, Somatosensory = motion↓

(Downward speed becomes constant because of air resistance)

Skydive Lillo Centro de Paracaidismo

Visual, Vestibular, and Somatosensory information

Drop1: Vestibular = 0G, Somatosensory = motion↓ (wind)

Drop2: Vestibular = 1G↓, Somatosensory = motion↓

(Downward speed becomes constant because of air resistance)

Parachute1: Vestibular = xG↑, Somatosensory = motion↓ + hanged

Parachute2: Vestibular = 1G↓, Somatosensory = motion↓ + hanged

Visual, Vestibular, and Somatosensory information

Drop1: Vestibular = 0G, Somatosensory = motion$\downarrow$ (wind)

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Parachute1: Vestibular = xG$\uparrow$, Somatosensory = motion$\downarrow$ + hanged

Parachute2: Vestibular = 1G$\downarrow$, Somatosensory = motion$\downarrow$ + hanged

http://www.ultravr.org/virtualreality/top-things-to-do-virtual-reality/

Visual, Vestibular, and Somatosensory information

Space: Vestibular = 0G, Somatosensory = Neutral
(no pressure from any direction)

Visual, Vestibular, and Somatosensory information

Space: Vestibular = 0G, Somatosensory = Neutral
(no pressure from any direction)

This situation can be roughly emulated in an airplane dropping down
(see https://youtu.be/LWGJA9i18Co).

http://www.faust-ag.jp/soul/adventure/soul142.php

Visual, Vestibular, and Somatosensory information

Stimulating all the sensory systems properly in VR is still a difficult problem. Especially, a viewing position is forced to change quickly by some outside factor.

https://youtu.be/q4ZfnZf8osA

Visual, Vestibular, and Somatosensory information

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http://japanese.engadget.com/2016/04/12/vr-vr-zone-project-i-can/

Visual, Vestibular, and Somatosensory information

Stimulating all the sensory systems properly in VR is still a difficult problem. Especially, a viewing position is forced to change quickly by some outside factor.

Problems of VR

VR-sickness (Cyber-sickness)

Its "reported symptoms include stomach awareness, burping, salivation, drowsiness, nausea and occasionally even vomiting, as well as disorientation, dizziness, headaches, difficulty focussing, blurred vision, and eyestrain" (Barrett, 2004, see also Read et al., 2015).

A user of a head-mounted display should take a rest without wearing the head-mounted display every 20 minutes (Kennedy et al., 2000) or whenever she/he experiences any nausea (Hu & Hui, 1997).

VR-sickness (Cyber-sickness)

Sources and potential sources of VR-sickness

1) Conflict among Visual, Vestibular, and Somatosensory information
2) Latency between head-motion and update of an image
3) Slow Screen refresh-rate
4) Low Screen resolution
5) Narrow Field of View

} Display

6) Constant lens accommodation
7) Approximate model of the eye

} Eye-ball

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(3)–5): Display)

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(6)–7): Eye-ball)

Problems 1) and 2) are especially critical for VR-sickness.

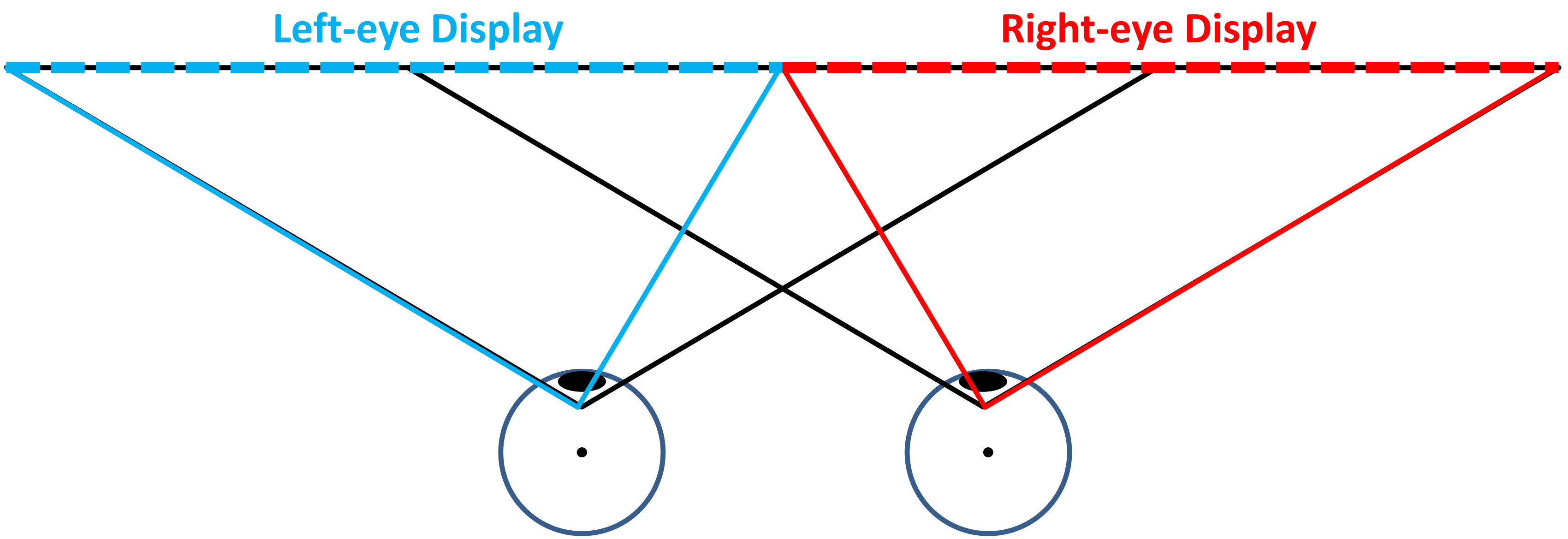
Problems 2), 3), 4), and 5) are technical. These problems are becoming and will be resolved.

Problems 6) and 7) may be factors causing VR-sickness. But, they are theoretically difficult to be studied and to be resolved.

Technical Problems

2) Latency between head-motion and update of an image
3) Slow Screen refresh-rate
4) Low Screen resolution
5) Narrow Field of View

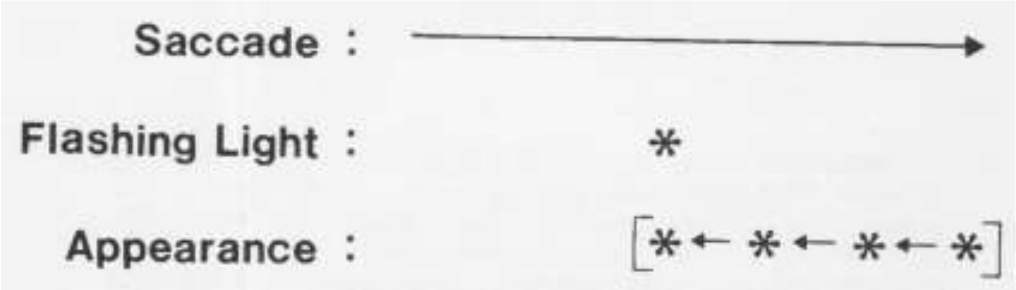
Solution-2: Good computer
Solution-3-4: Good display
Solution-5: Nasal side of visual field?

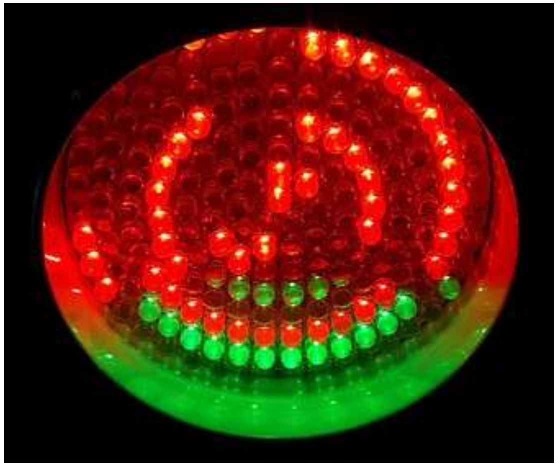


Screen Refresh-rate and Flicker fusion threshold

Refresh-rate of a computer display is often discussed based on psychophysical results of the *flicker fusion threshold*.

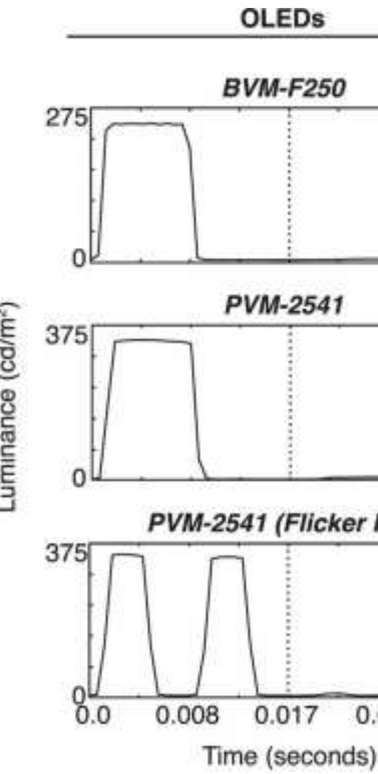
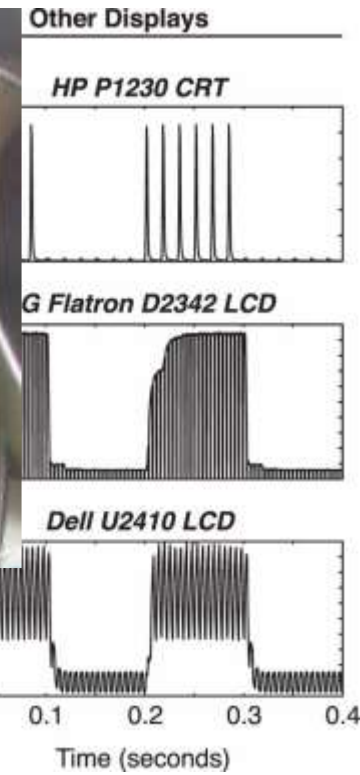
It has been considered that 60 Hz is high enough for a display. But, recent studies suggest that the temporal resolution of the human visual system can be much higher depending on visual stimuli (Davis, Hsieh, & Lee, 2015) and on eye-movements (Hershberger & Jordan, 1998).

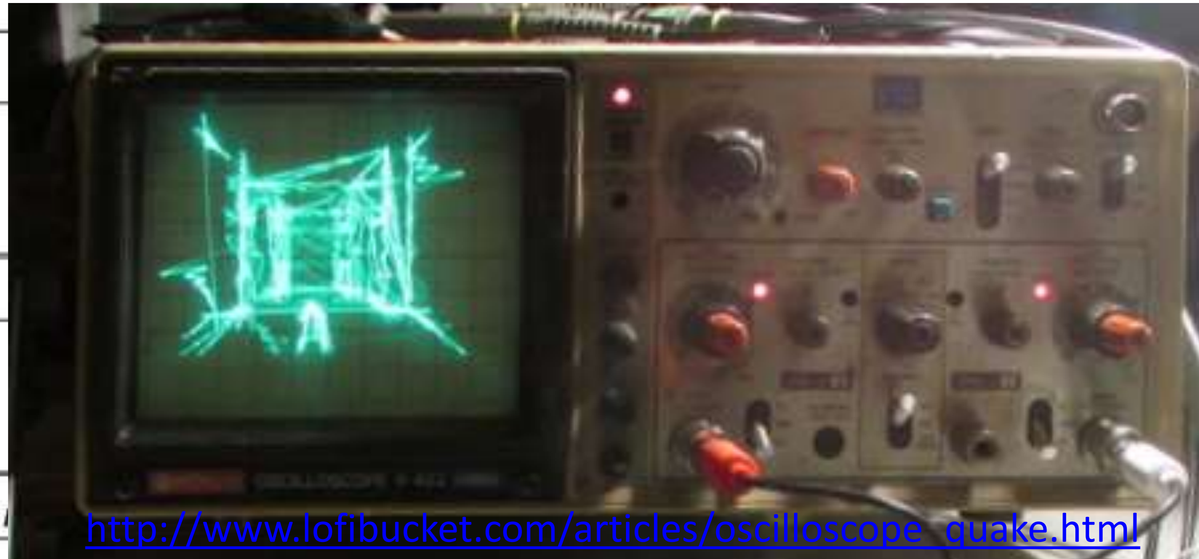




By Artem Svetlov

Screen Refresh-rate



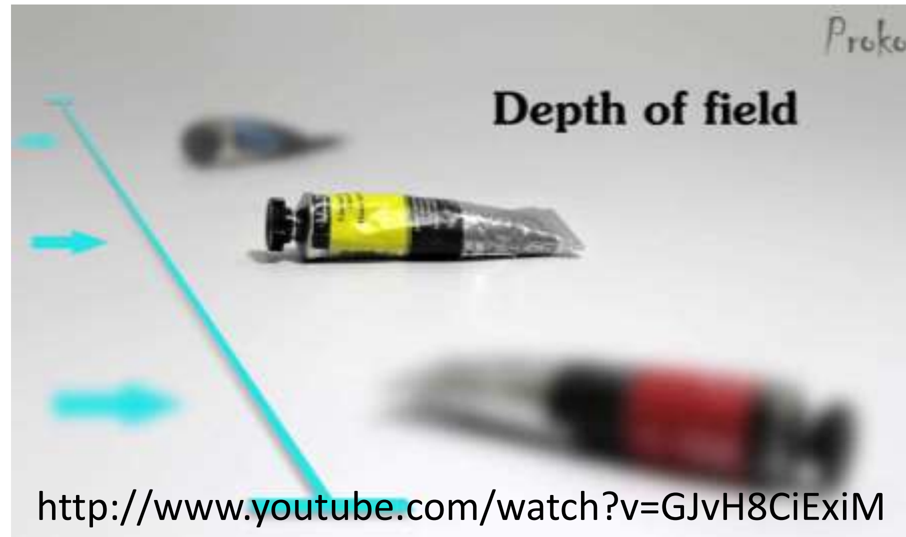
http://www.lofibucket.com/articles/oscilloscope_quake.html

e.g. Nagasaka & Wasserman (2008)

Cooper et al. (2013)
http://jov.arvojournals.org/article.aspx?articleid=2121369

Accommodation and Image-blur

If a lens of your eye focuses at some object, other objects at different distances (closer/further) will be blurred in your retinal image.



http://www.youtube.com/watch?v=GJvH8CiExiM

If the objects are placed at 20cm and 50cm, their images can be blurred very differently (it depends on where you focus and your pupil size).

If the objects are placed at 2m and 5m, their images will be almost equally blurred (or equally focused).

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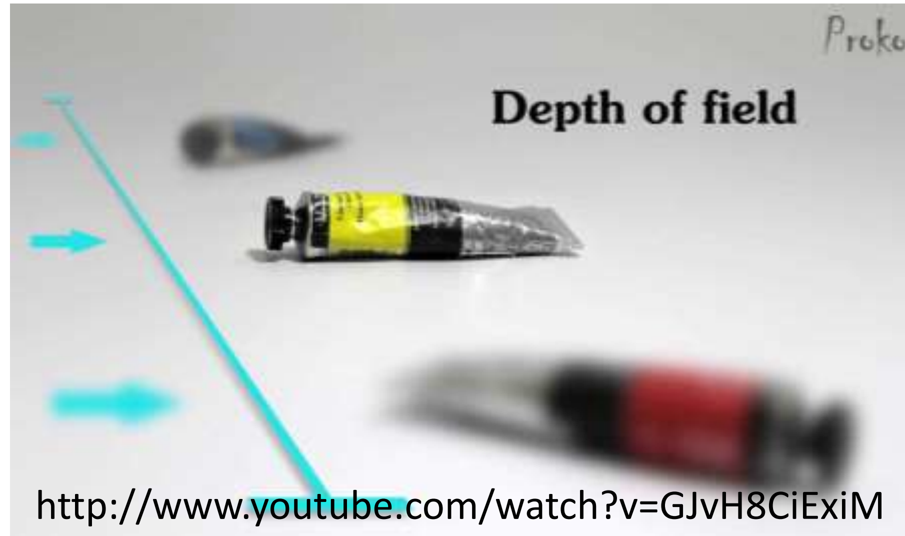


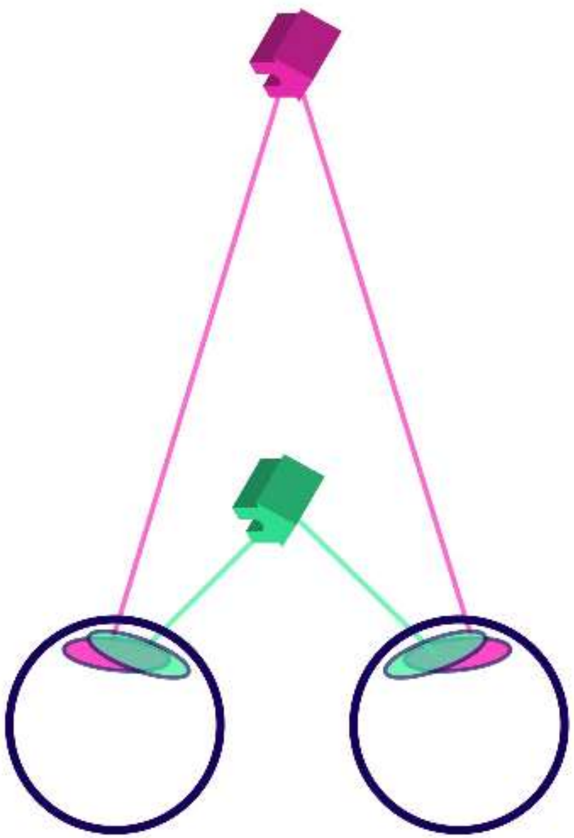
http://www.youtube.com/watch?v=GJvH8CiExiM

Using the current common head-mount display, an eye-lens always focuses at a fixed distance (display + display-lens) no matter how close/far something appears.

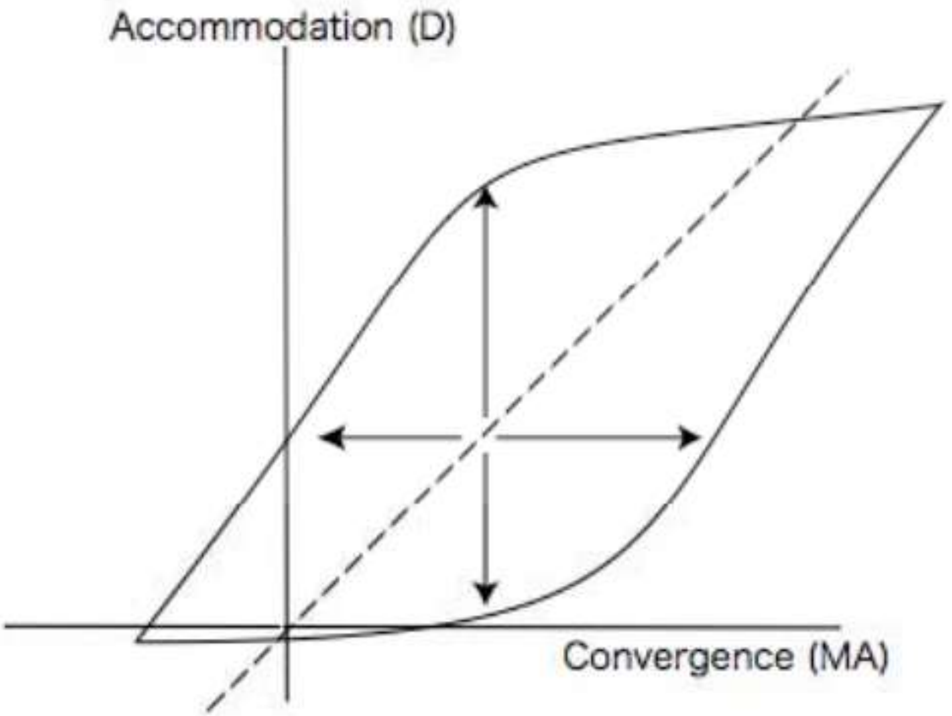
Accommodation vs. Vergence

Two types of accommodation:

- Convergence-driven accommodation (driven by oculomotor info)
- Defocus-driven accommodation (minimizing image blur)



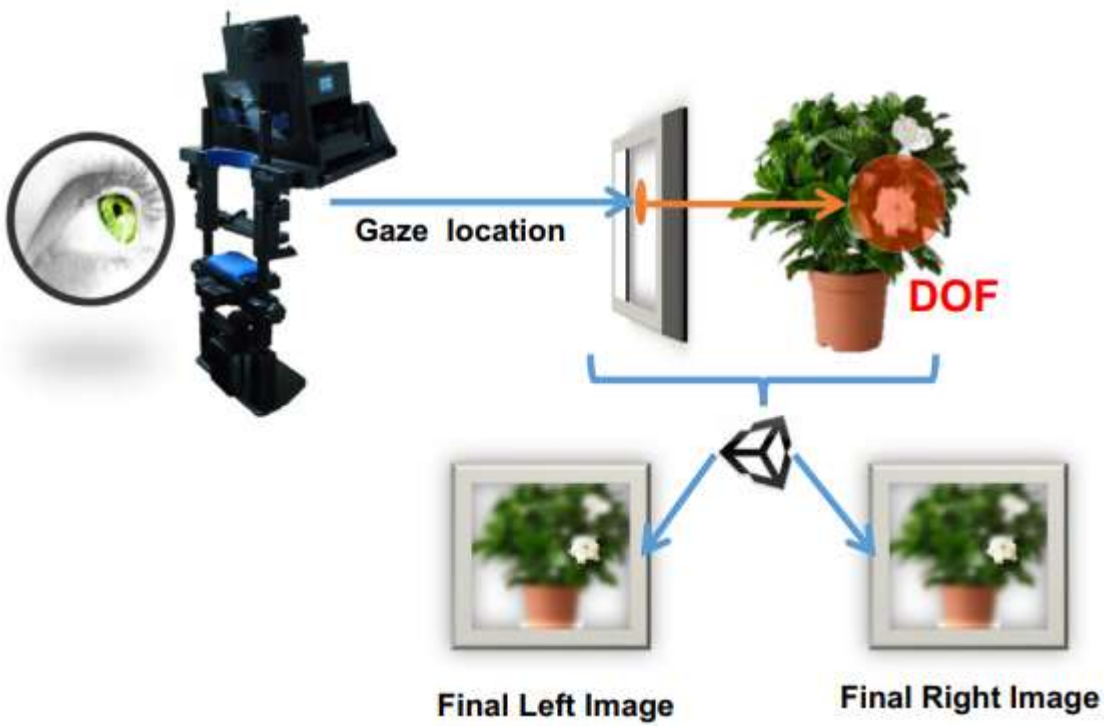
https://uxdesign.cc/human-eyes-understanding-of-space-for-augmented-reality-d5ce4d9fa37b



Ukai (2006)

Accommodation and Image-blur

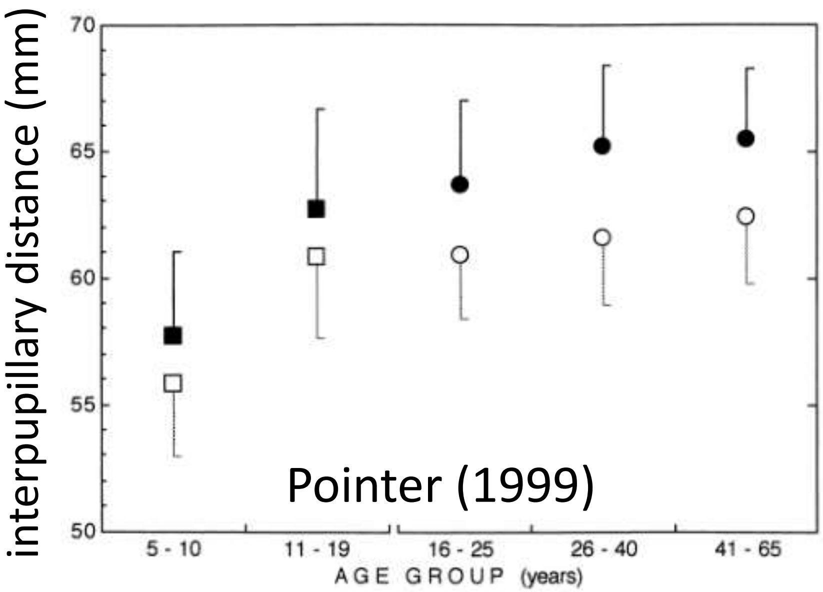
Emulating depth-of-focus is not critical to improve experience of a 3D display (Vinnikov, Allison, & Fernandes, 2016).

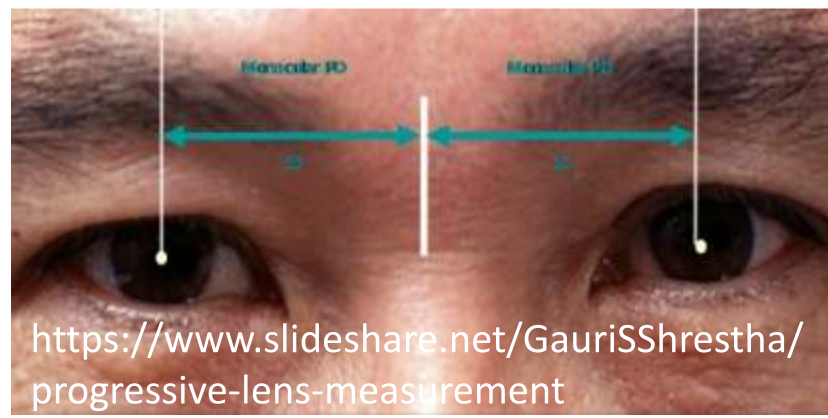


Age limit for 3D contents?

e.g. Sony PSVR (12yo), Oculus-rift (13yo), Nintendo 3DS (6yo)

Inter-pupillary (inter-ocular) distance increases as a person gets older.

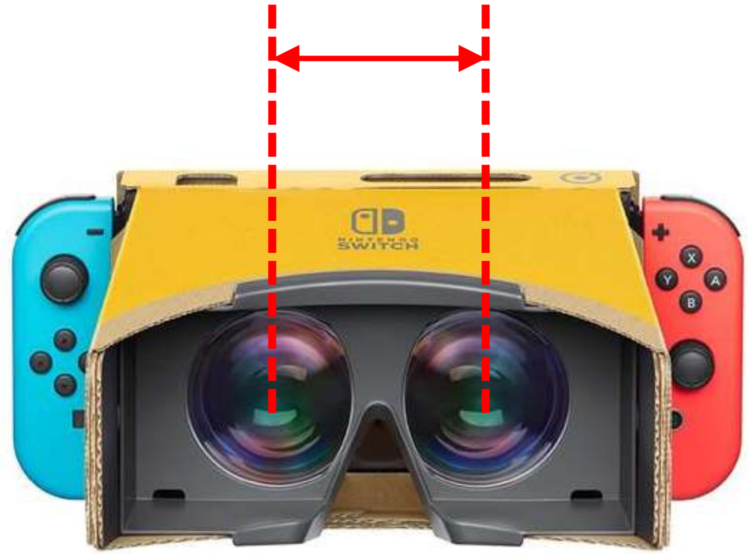




The visual system of children for stereo vision should be plastic in some aspect to accommodate with the growing inter-pupillary distance.

Age limit for 3D contents?

e.g. Nintendo Lab: VR-kit (7yo)



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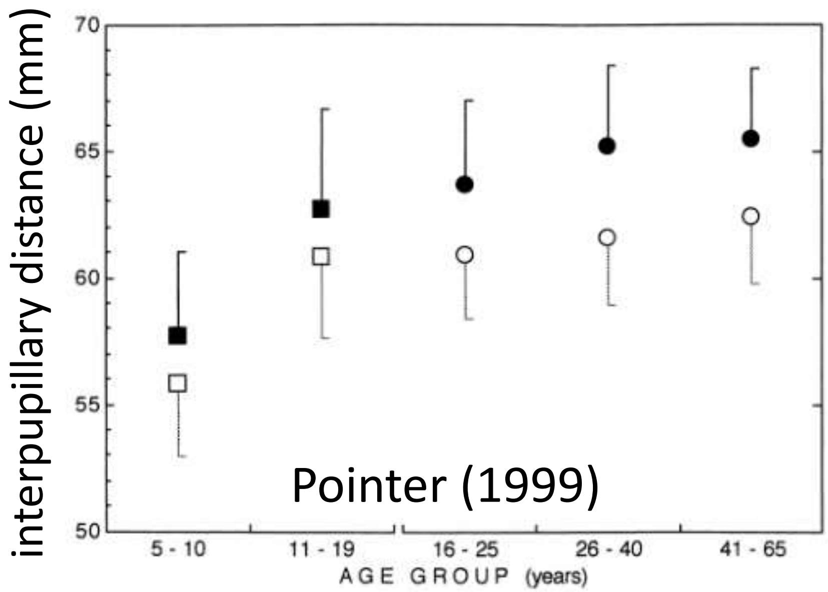

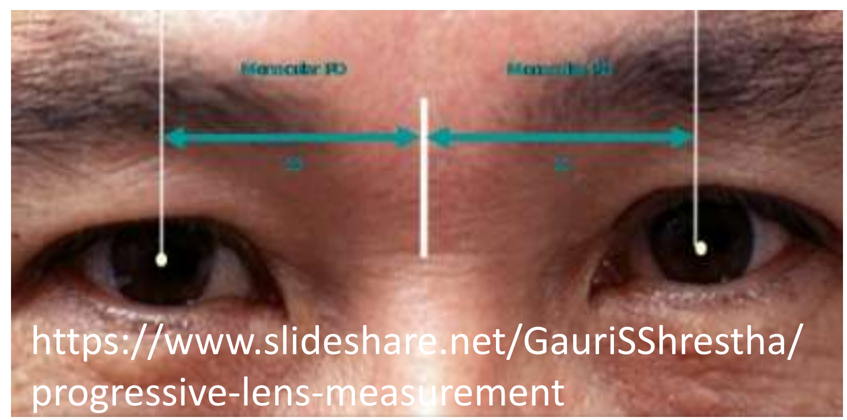

https://www.slideshare.net/GauriSShrestha/progressive-lens-measurement

The visual system of children for stereo vision should be plastic in some aspect to accommodate with the growing inter-pupillary distance.

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Strabismus is developed before 6 years old of life (Hollwich, 1983/1986).
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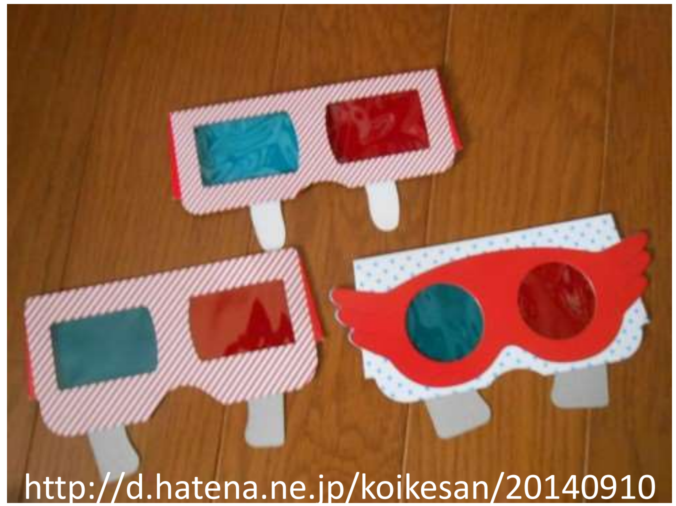


At least, there is one case report (Tsukuda & Murai, 1988). A 4yo child developed strabismus (*acute onset esotropia*) after watching a 3D movie (probably, 15 min long cartoon animation using anaglyph).

(This is just *a case report* and no other case is known.)

Age limit for 3D contents?

14min

Anaglyph (Red/Cyan)

Only crossed disparity (objects popped out from a physical screen.)

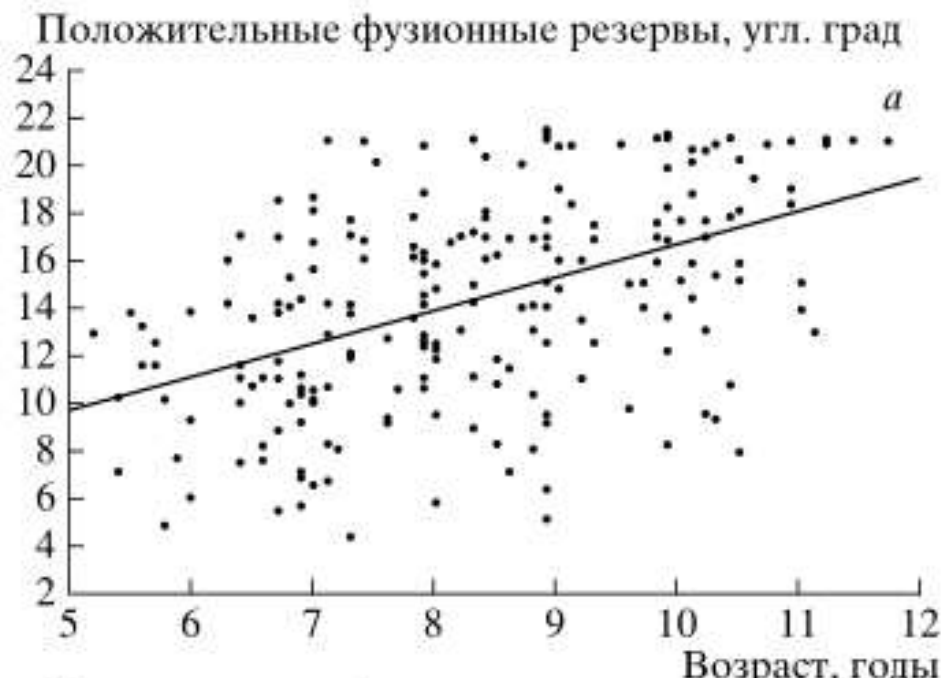
Screened with two 2D movies (97min and 43min)

See Tsukuda & Murai (1988), Zone (2012)

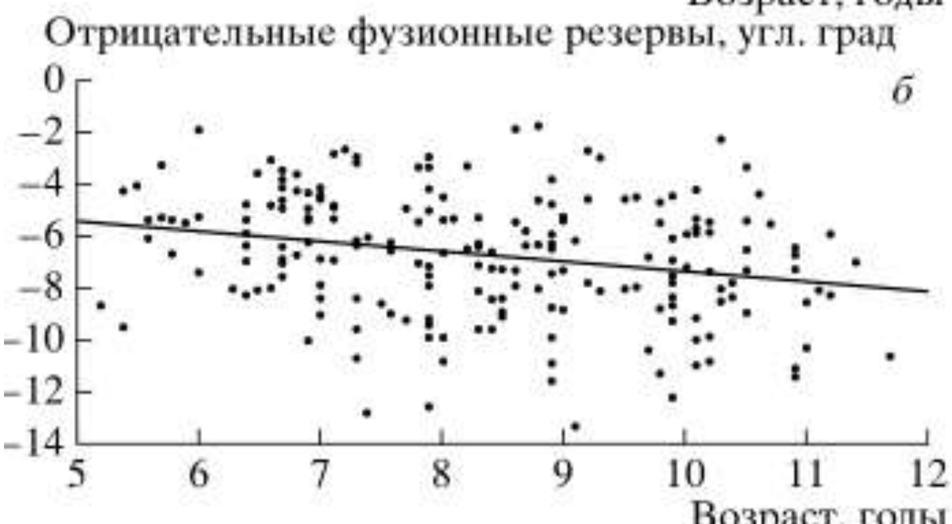
http://k-cart.com/ca18/30241/

Age limit for 3D contents?

Vasilyeva & Rozhkova (2009)



Convergence



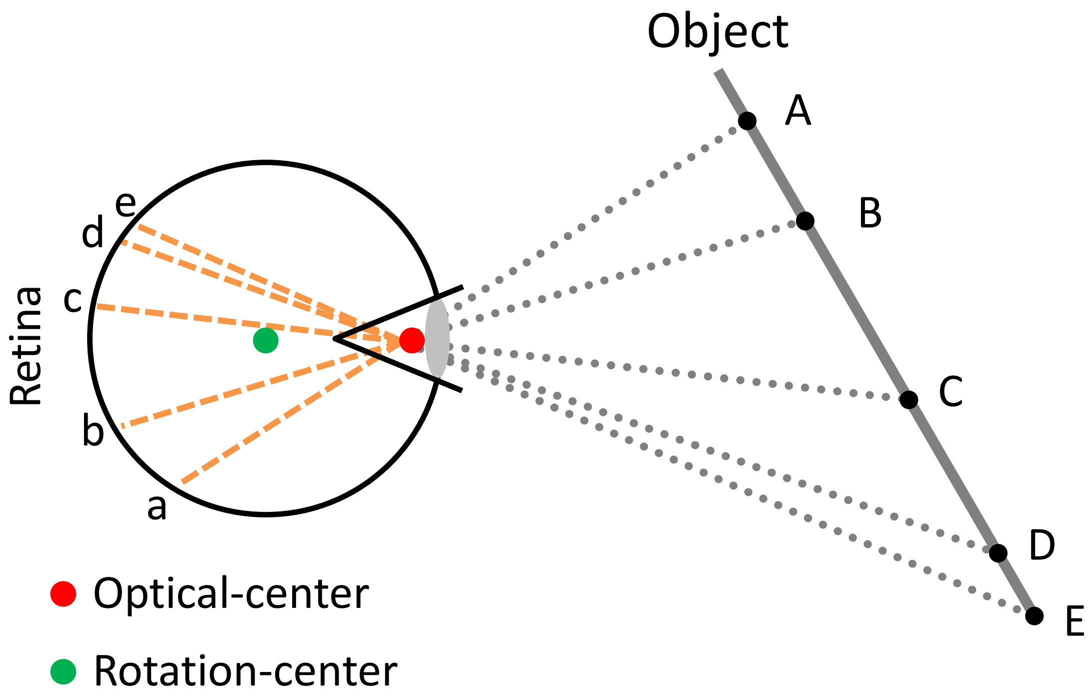
Divergence

Most of head-mounted displays are designed for an adult person assuming that an inter-ocular distance is ≈ 6.5cm. VR contents are usually rendered assuming these displays.

They can induce divergent eye-movement for children, which rarely happens in our everyday life.

Two centers of the eye

The human eye has two centers: centers of optics and of rotation.



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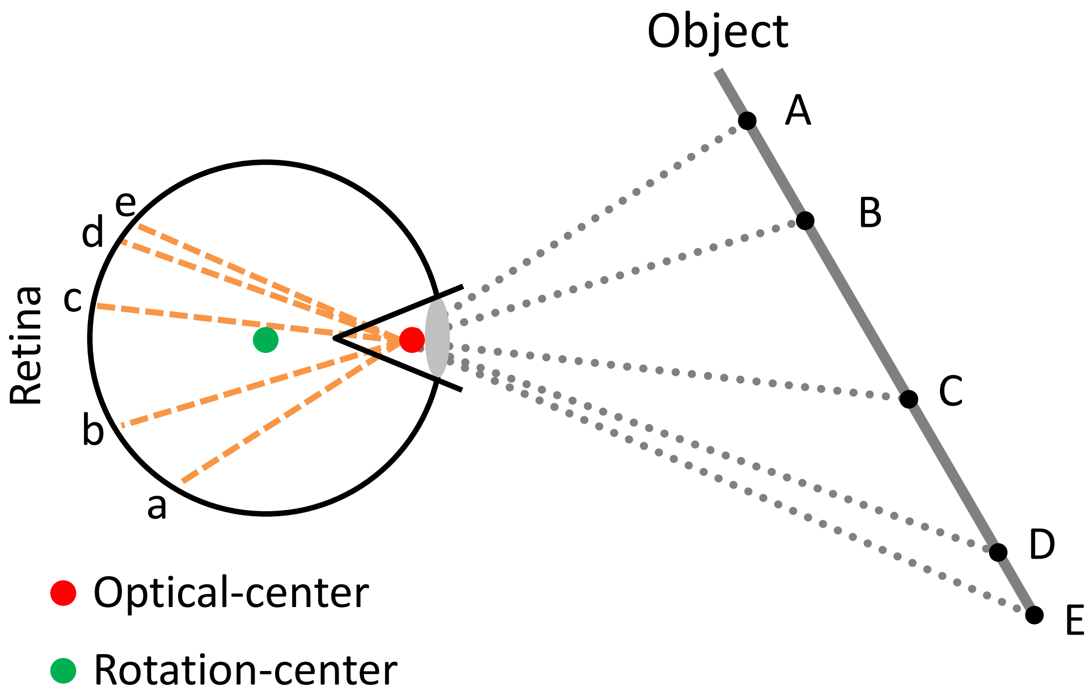
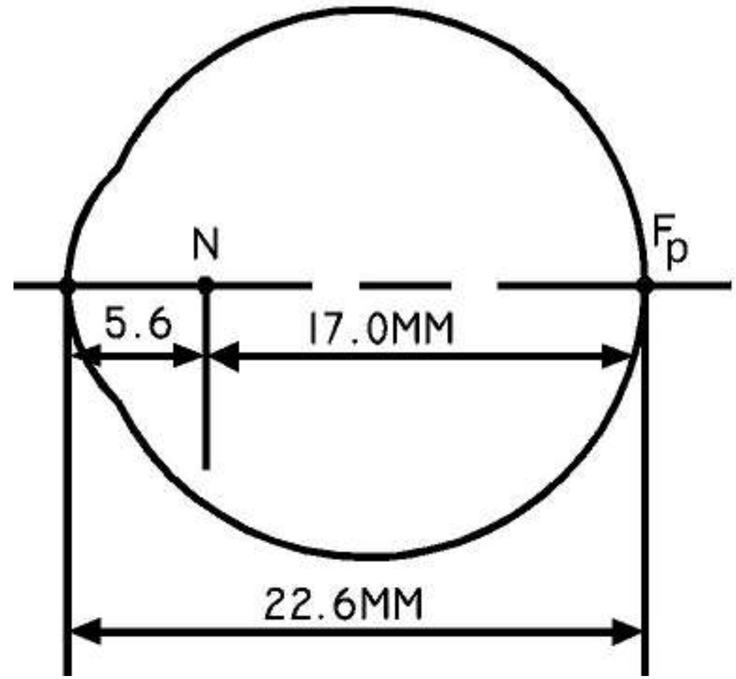
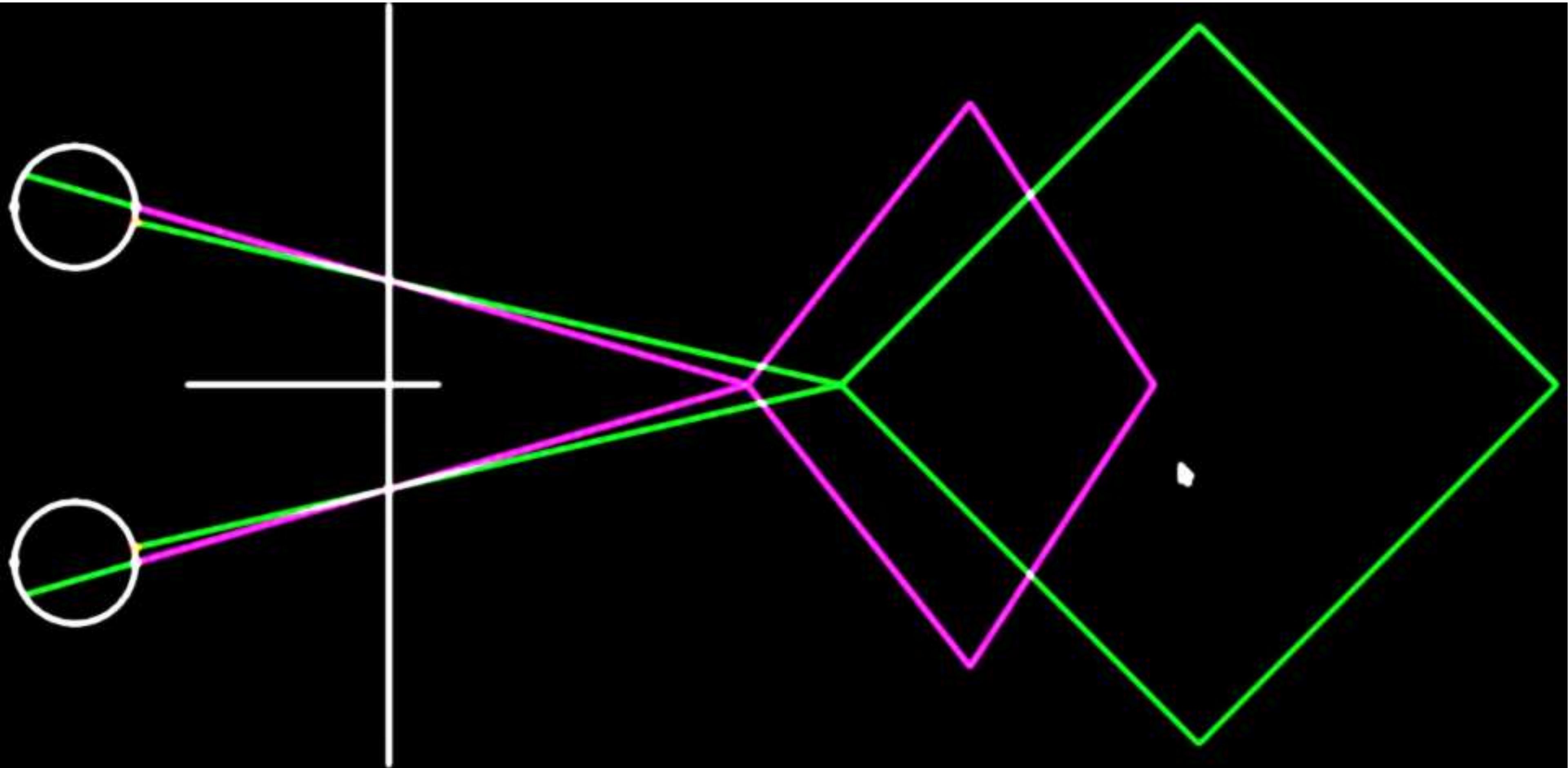




The distance between these two centers is around 6.3mm (Optometry, average-nodal-point, Tschermak-Seysenegg, 1952) or around 11mm (Behavioral-study, Bingham, 1993).

Two centers of the eye

This distance can be critical for head-mounted displays, whose screens are just a few cm away from the eyes.

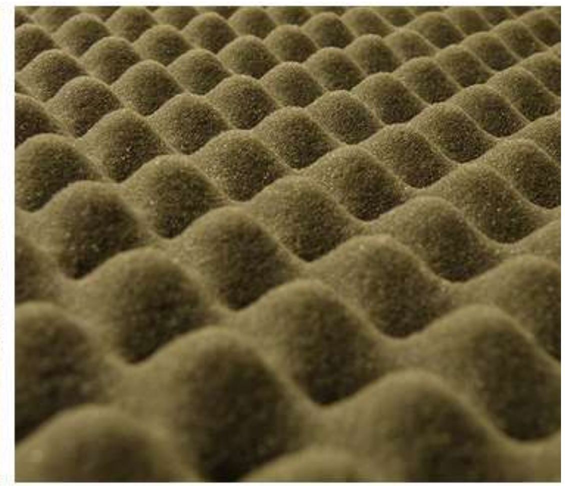


https://youtu.be/lsKuGUYXHa4; http://doc-ok.org/?p=756

Eye ≠ Pinhole camera

Perspective projection ≈ Projection from a 3D scene to a 2D retinal image

The model of the perspective projection assumes, so called, a pinhole camera. In reality, the eye's pupil (ø 2~9mm) is substantially bigger than a pinhole and it causes blur in the retinal image.



http://sploid.gizmodo.com/watching-geckos-pupils-contract-and-dilate-is-pretty-sa-1619442549

A Pair of Glasses / Contact-lenses?

Prescriptions for head-mounted displays for individual people?