Course on Virtual Reality

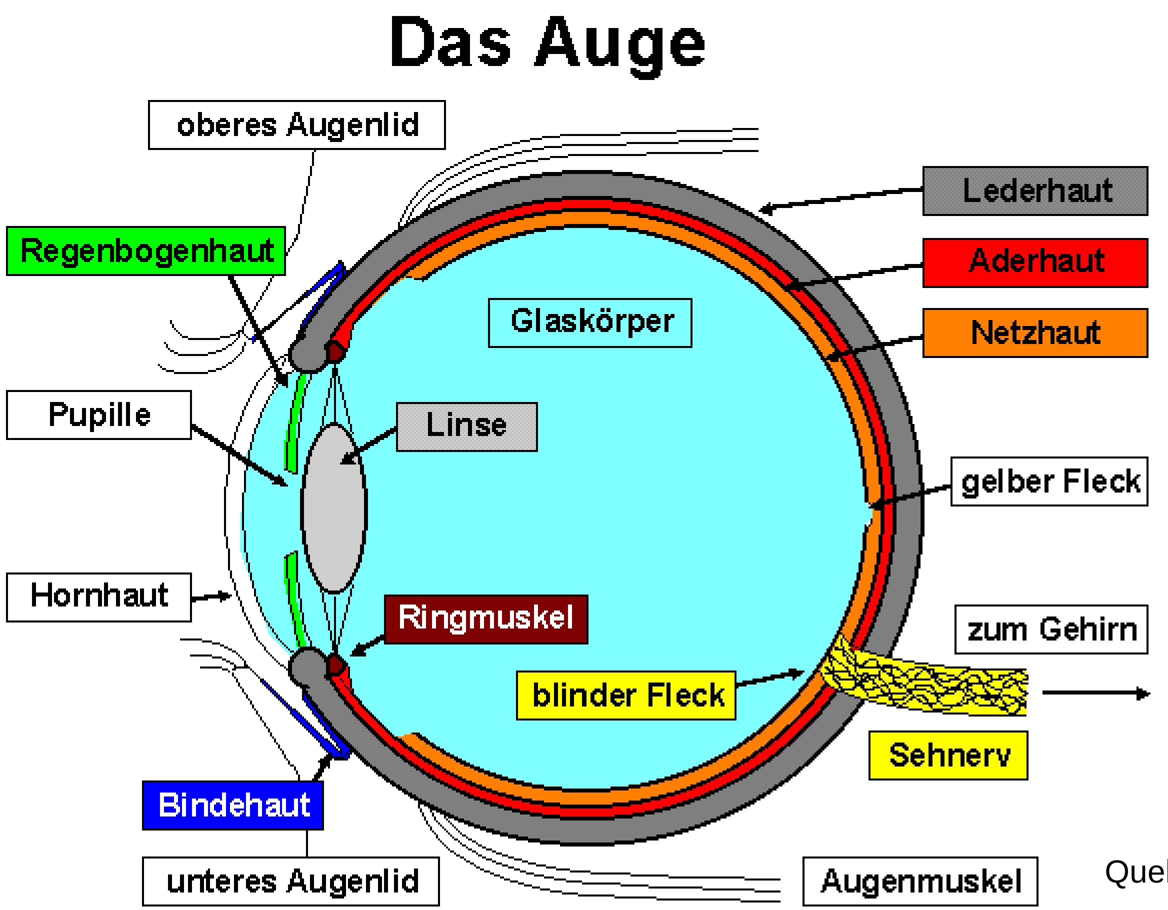
3-D Vision

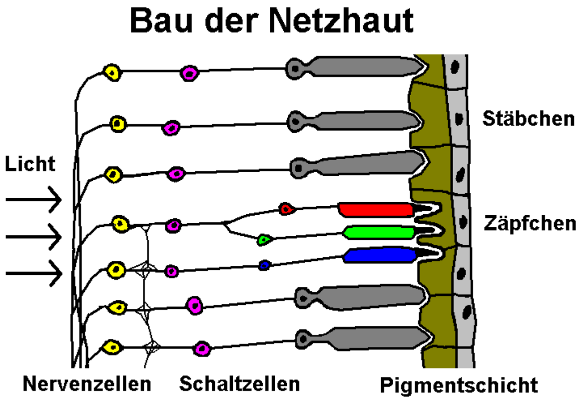
Visual Computing Institute

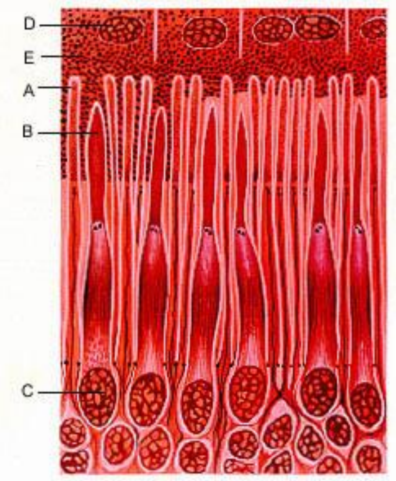
RWTH AACHEN UNIVERSITY

Exact correspondence of visual perception in the real world and in the virtual world

The Human Eye







Quelle: WWW

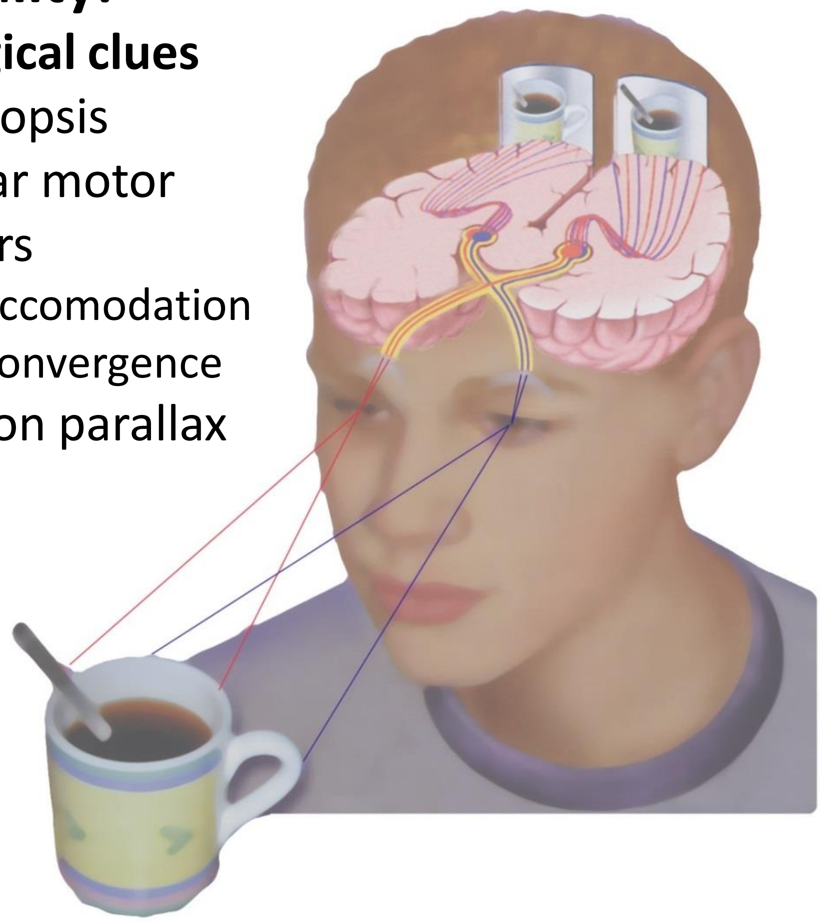
Physiological & Psychological Clues

Traditional CG:

- **Psychological clues**
  - Perspective shortening
  - Occlusion of objects
  - Light and shadows
  - Texture gradients
  - Atmospheric perspective

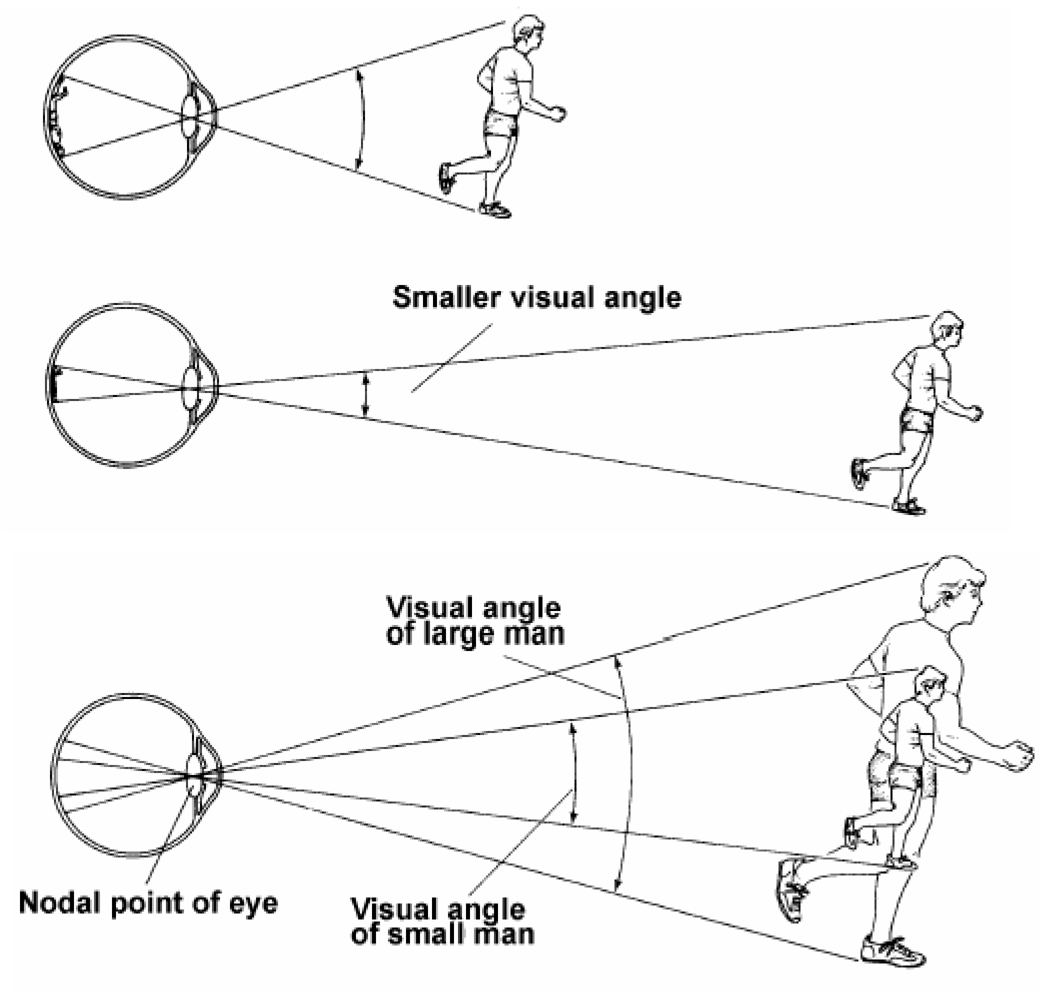
Virtual Reality:

- **Physiological clues**
  - Stereopsis
  - Ocular motor factors
    - Accomodation
    - Convergence
  - Motion parallax



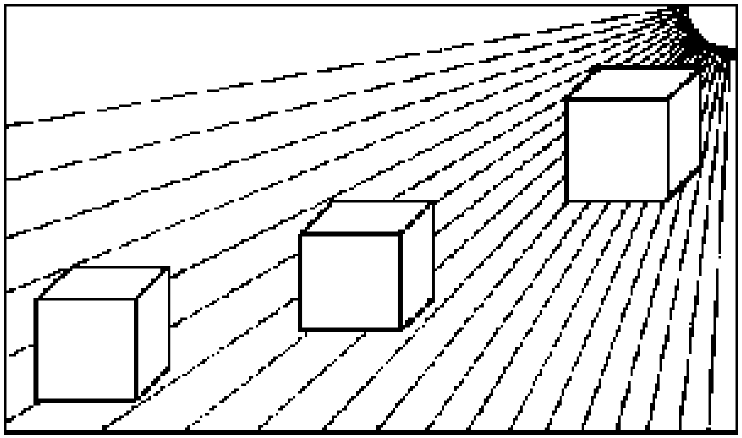
Perspective

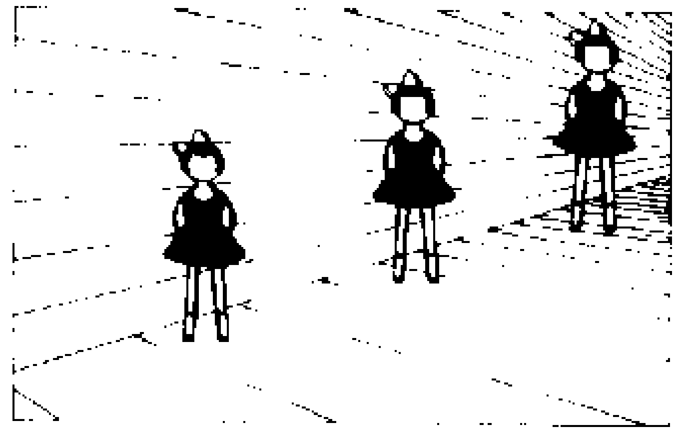
Drawing: Goldstein (WWW)

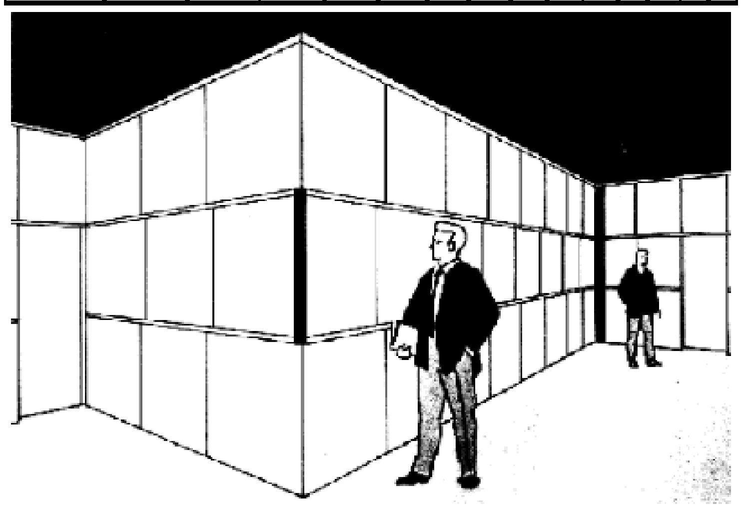


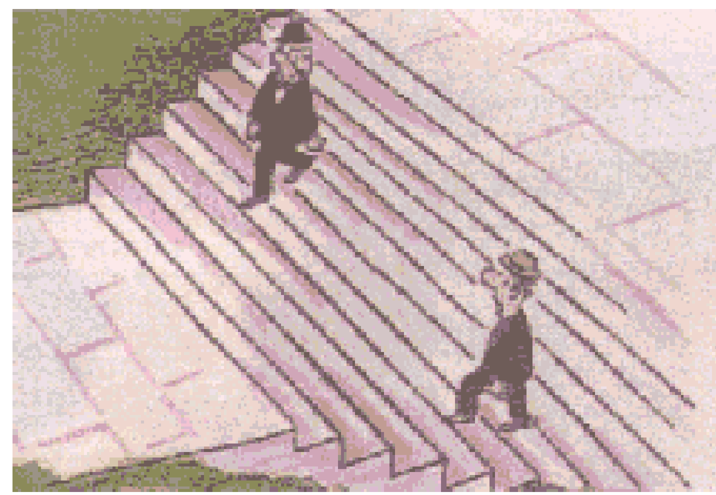
Optical Illusion based on Perspective

Drawing: Anonymous (WWW)



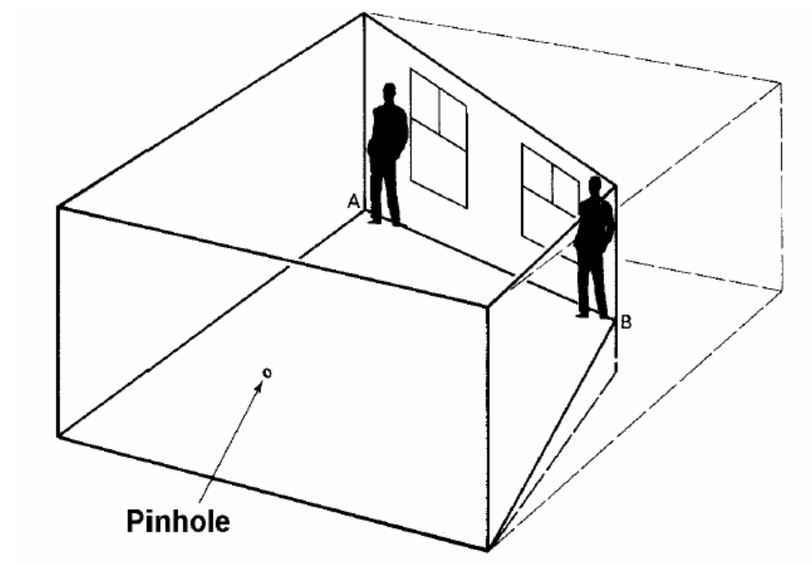






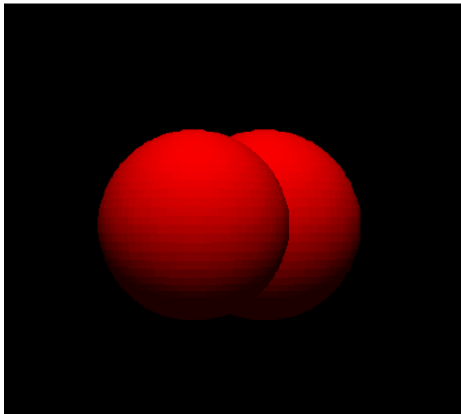
The Ames Room

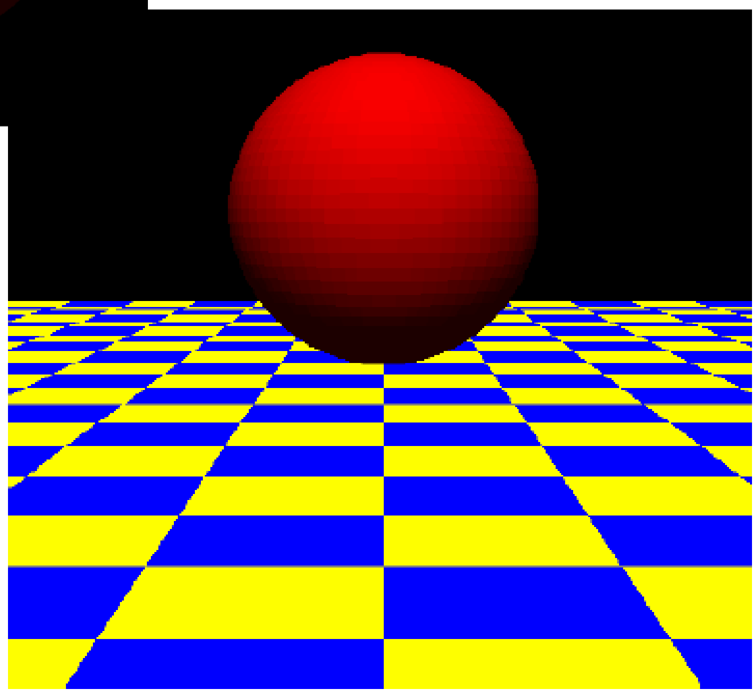
Pictures: Goldstein, Levine & Shefner (WWW)

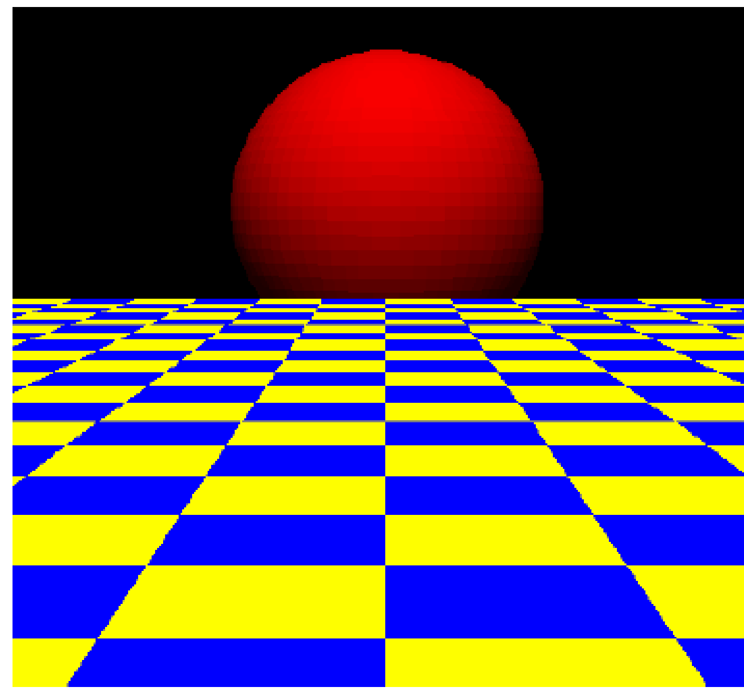


Occlusion

Pictures: Hübner (WWW)

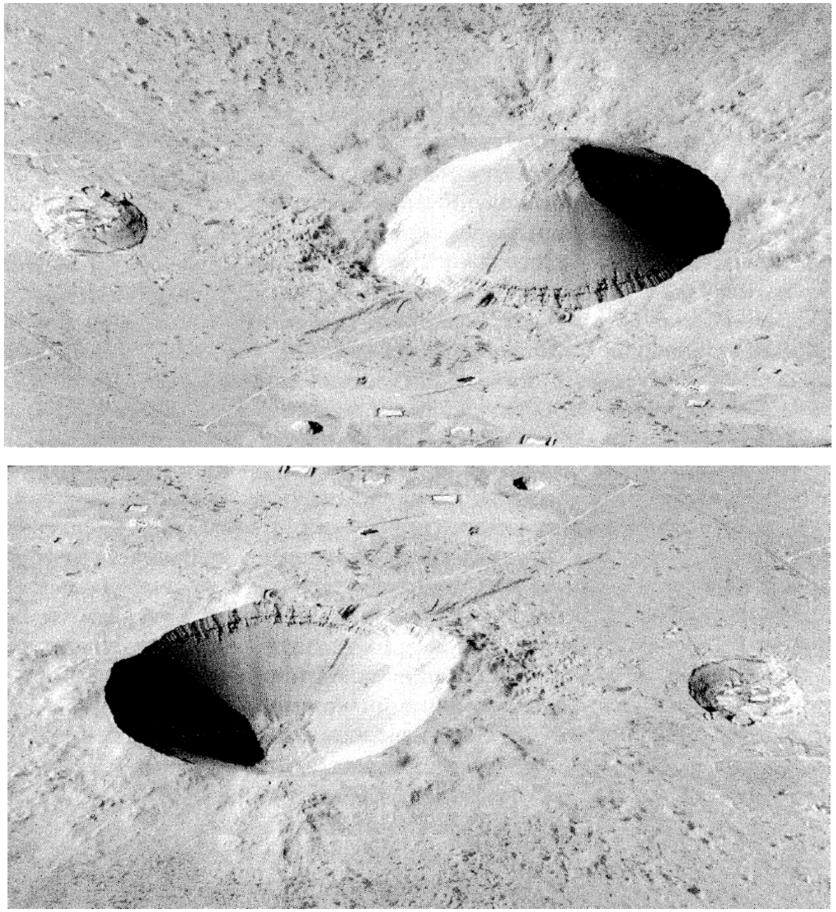






Light & Shadows

Pictures: Levine & Shefner (WWW)

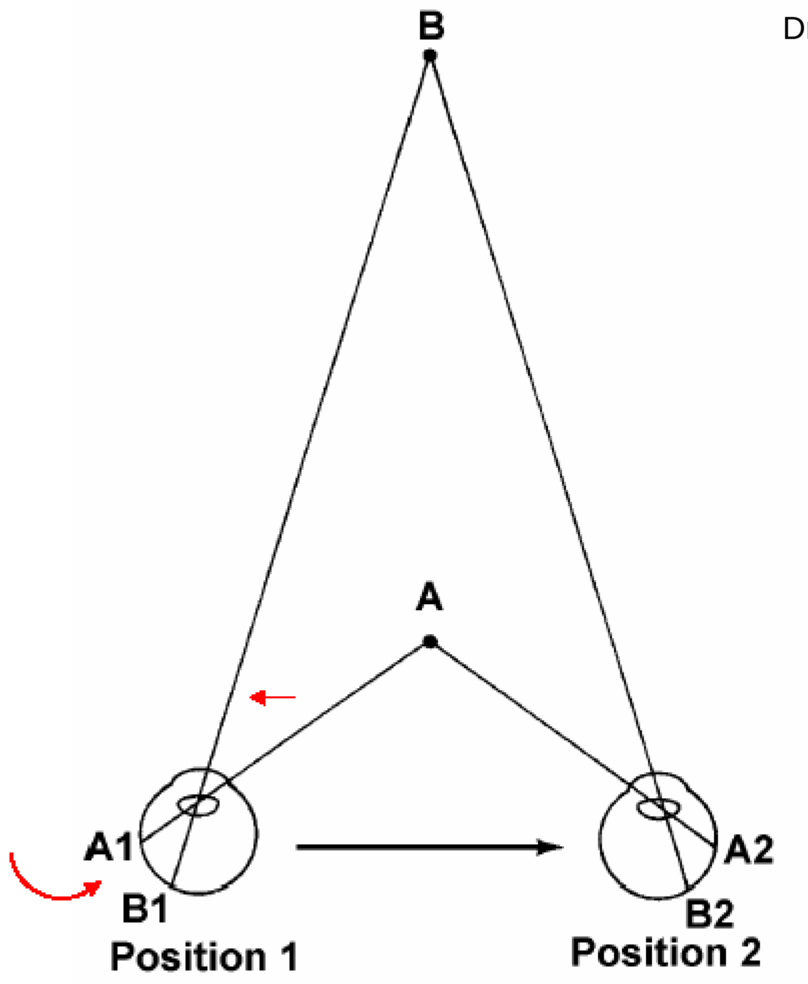


Atmospheric Perspective

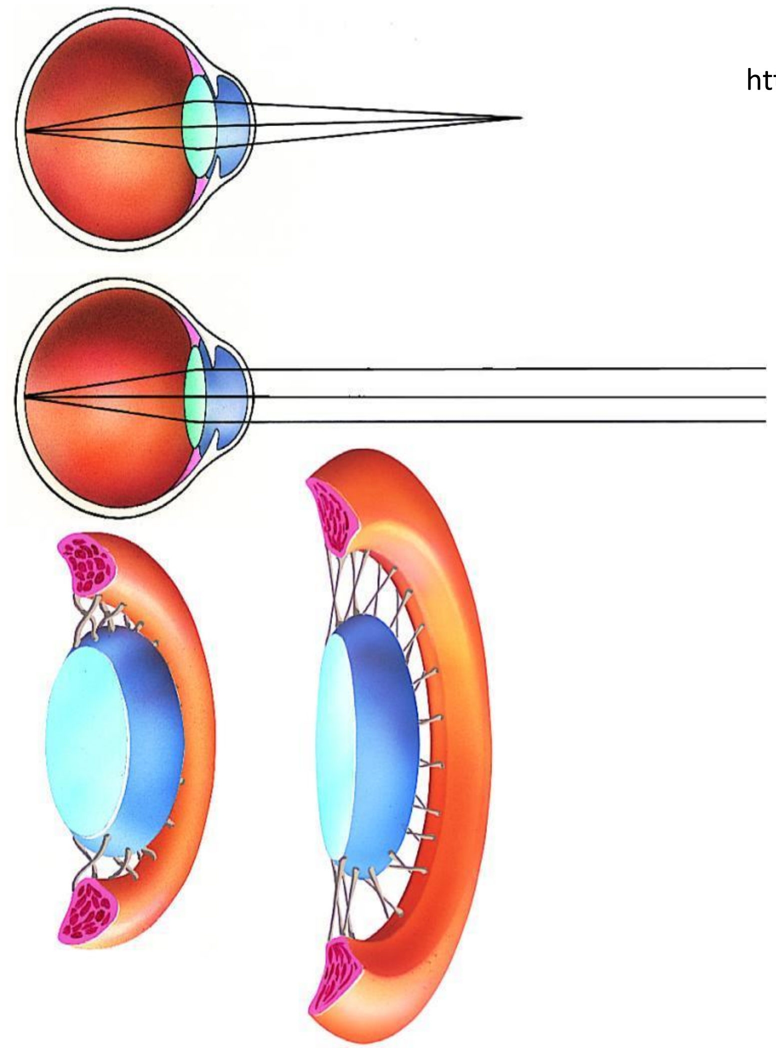
Picture: Lappe (2009)

Convergence

Drawing: Goldstein (WWW)

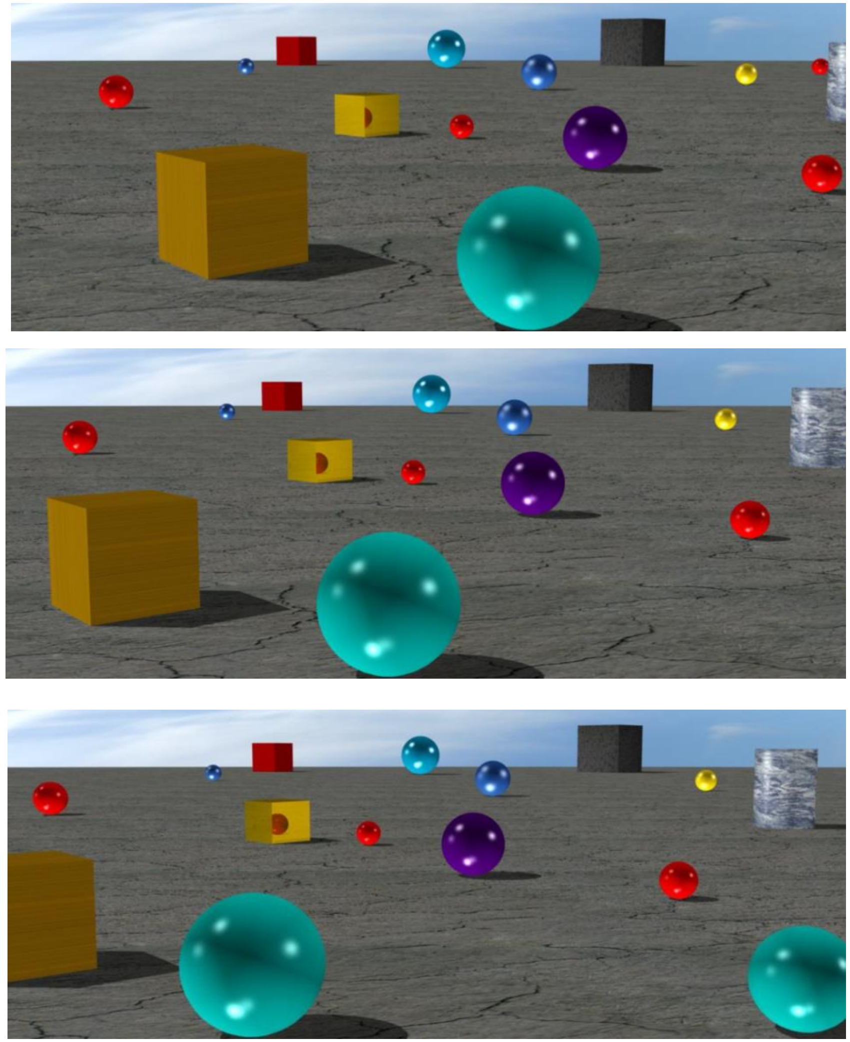


Accomodation



http://www.denstoredanske.dk

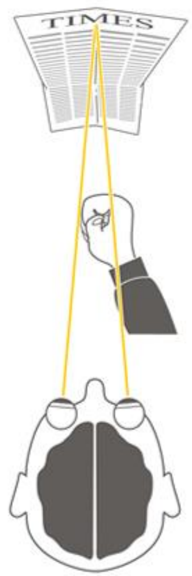
Motion Parallax



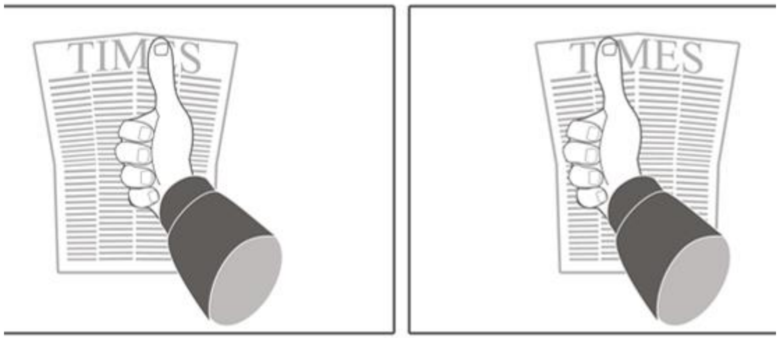
Tom Vaughan,
www.cyberlink.com

Stereoscopy

http://www.more3d.com/3-D/Stereoskopie.html



- Interocular distance (about 6 cm)
- Disparity of images projected onto the retina
- Processing in the visual cortex of the brain
- Works for distances up to 7 m



Field of View

Riecke (2006)

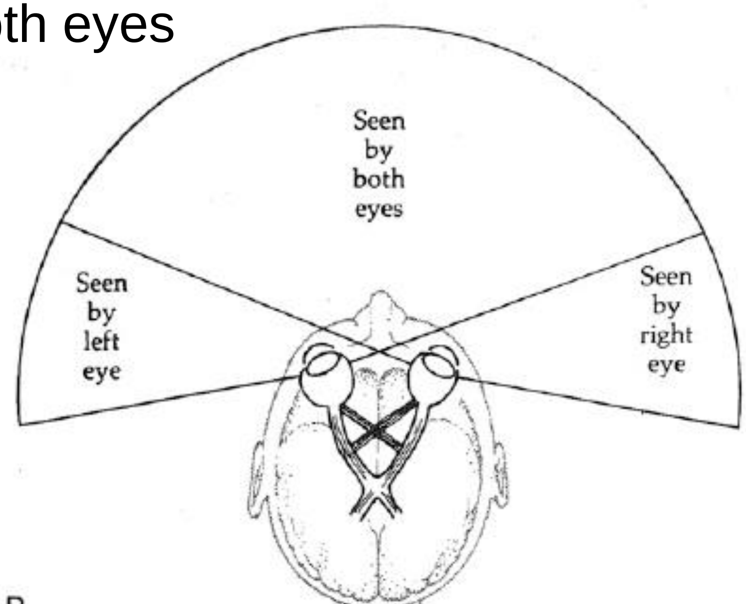
- Oval shape
- At eye level:

  Horizontal: About 90° to both sides

  Vertical: About 120° (h 50° and i70°)

- FOV center is being perceived by both eyes

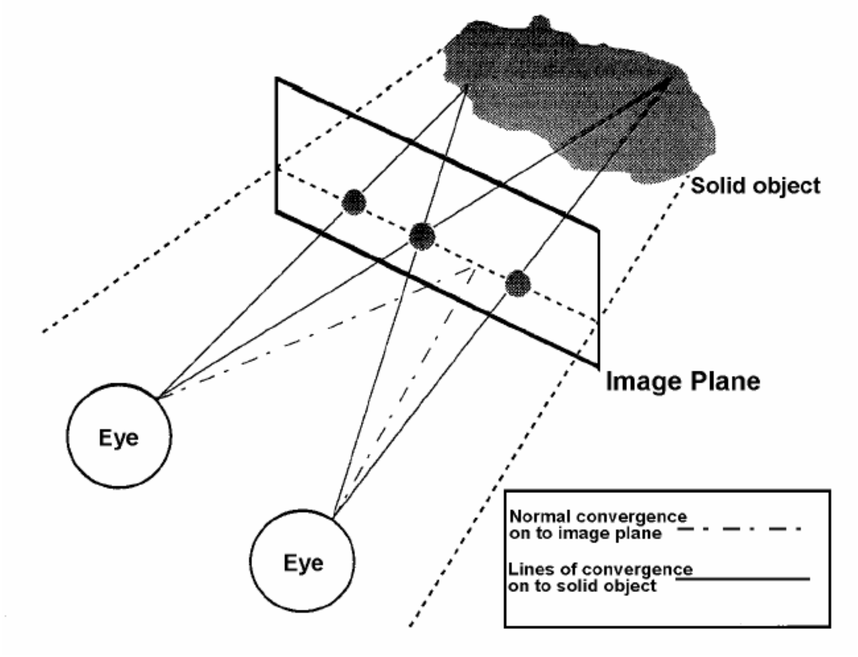
  Stereoscopic field: 100° - 120°

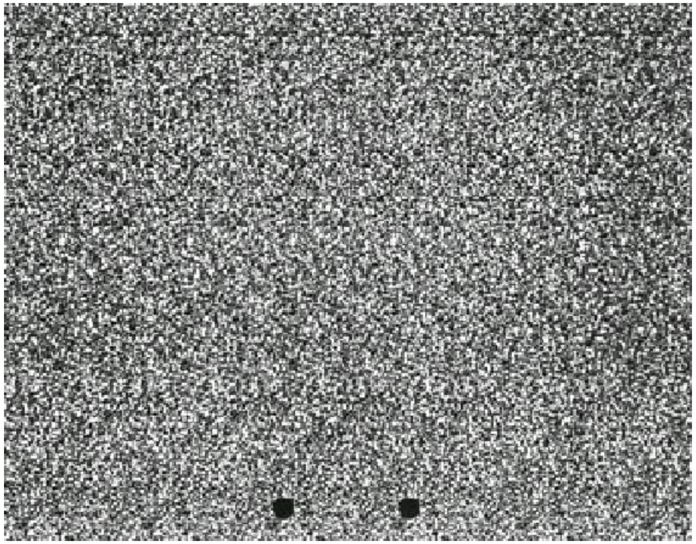


B

Auto-Stereograms

Drawing: Irtel (WWW)





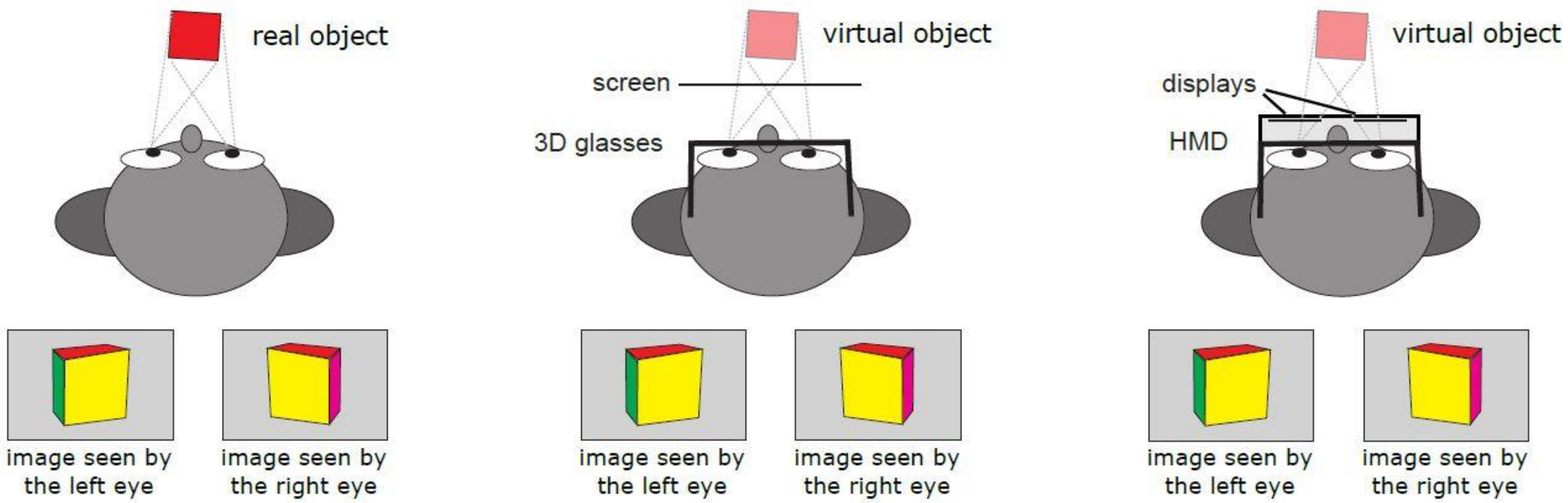
Auto-Stereograms (cont;-)

Picture: WWW

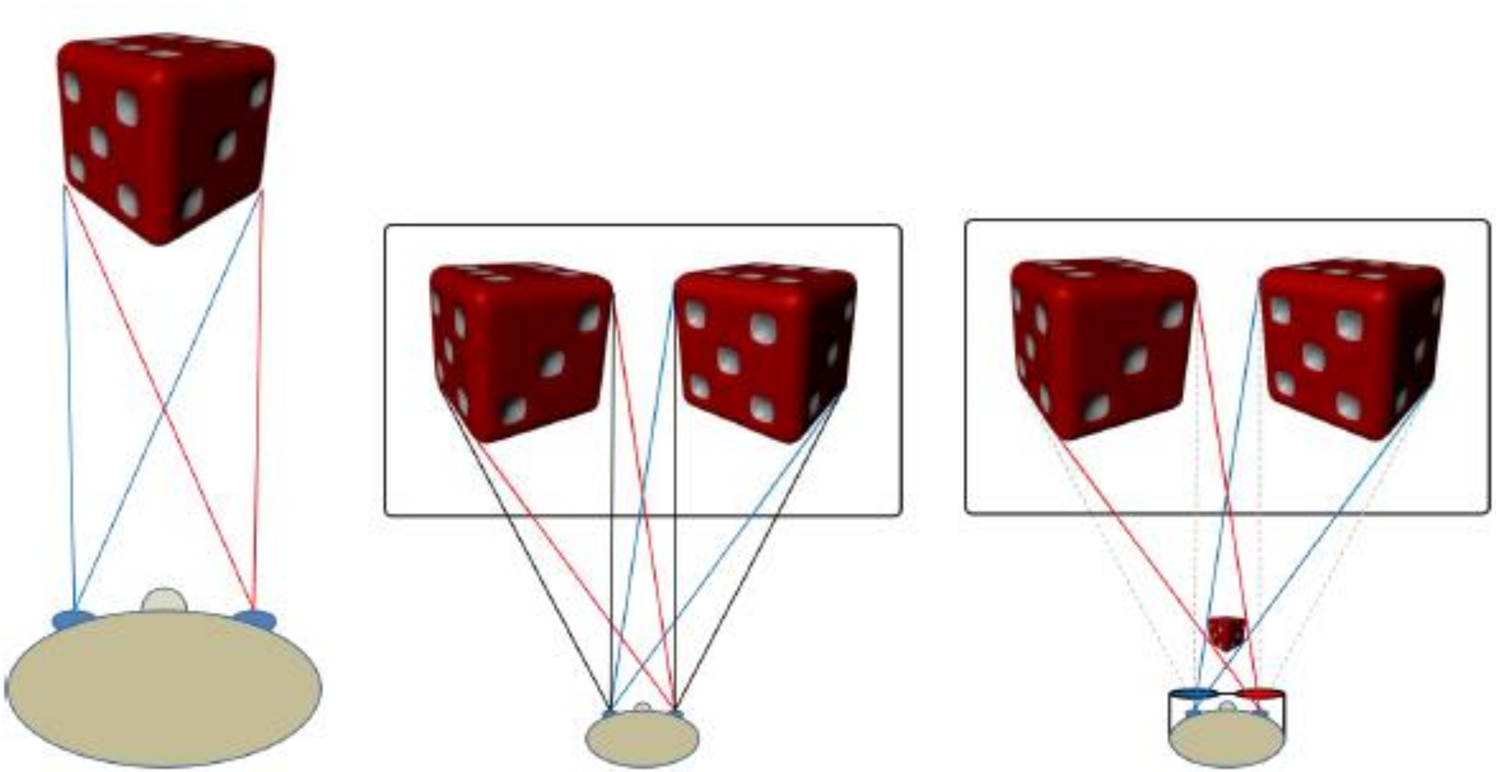
Look for several seconds at the pic

and you may recognize a giraffe!

Stereo in Head-Mounted &Room-Mounted Displays

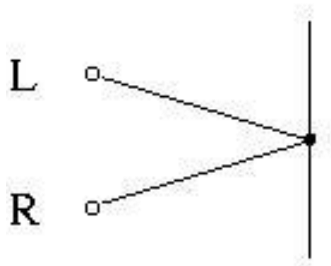


Stereo Parallax on Room-Mounted Displays

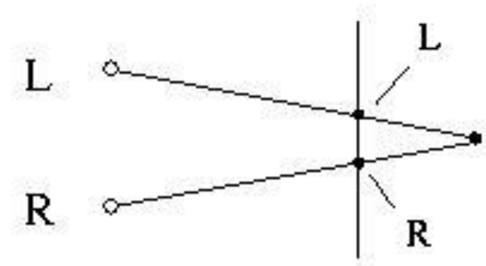


Tom Vaughan,
www.cyberlink.com

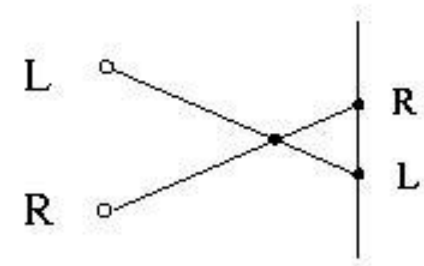
Stereograms



zero parallax

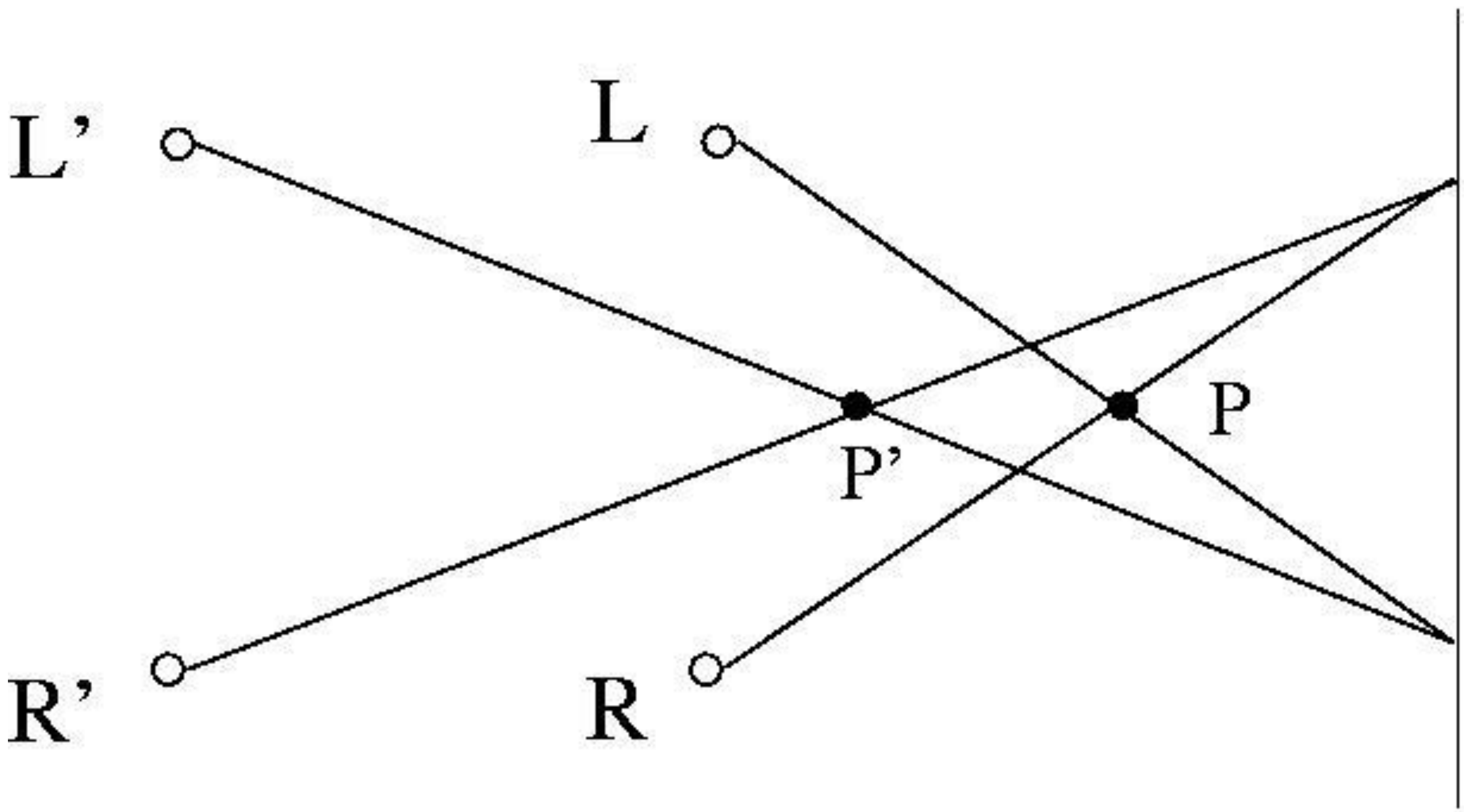


non-crossed
(positive) parallax

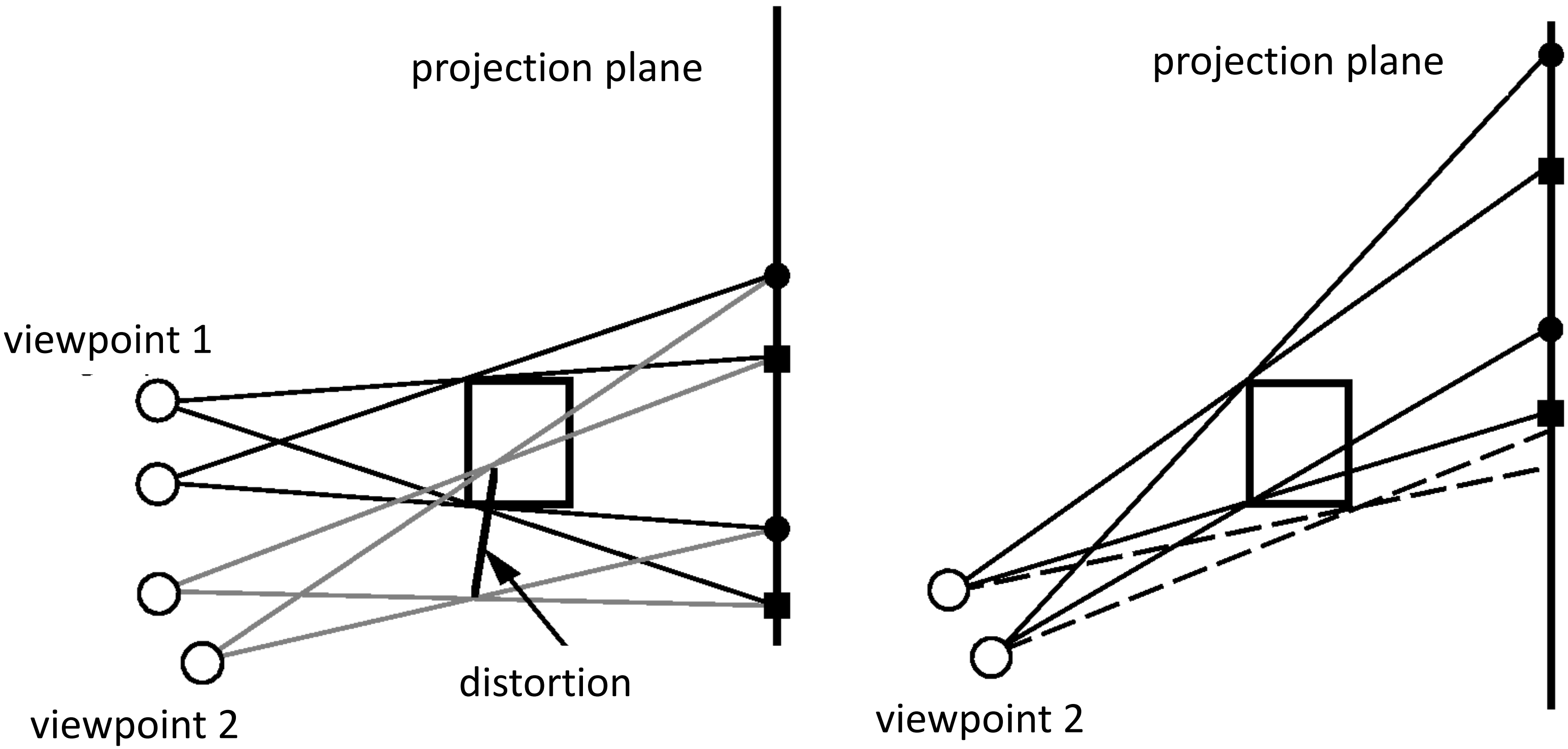


crossed
(negative) parallax

Distortions in Static Stereograms



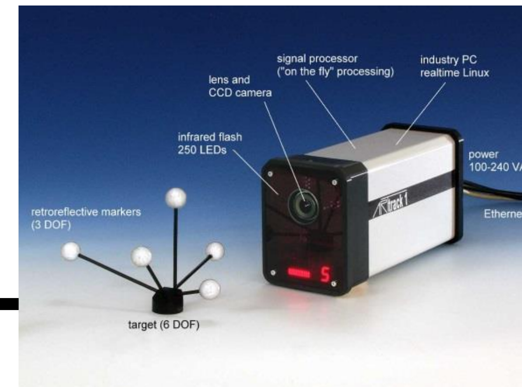
Adaptation of projection to the viewpoint

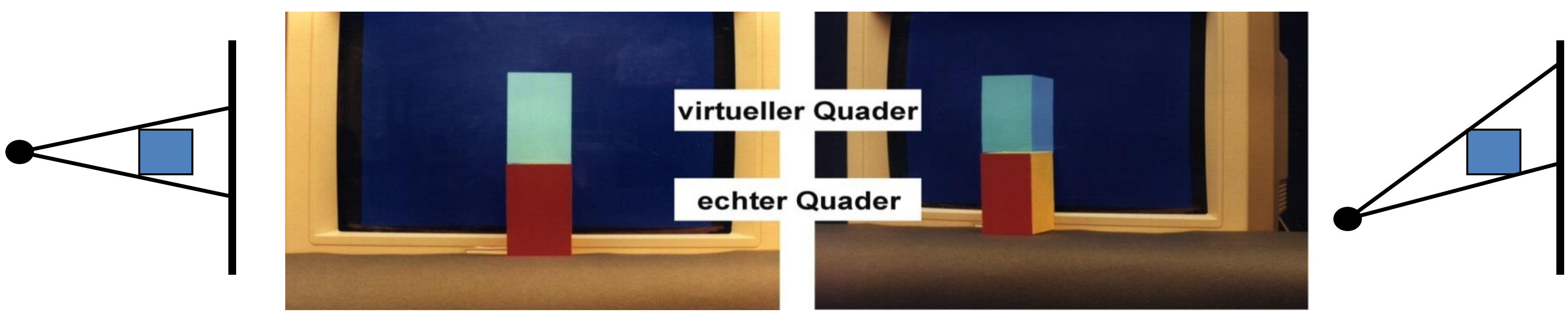


Motion Parallax & Viewer Centered Projection

stereo parallax

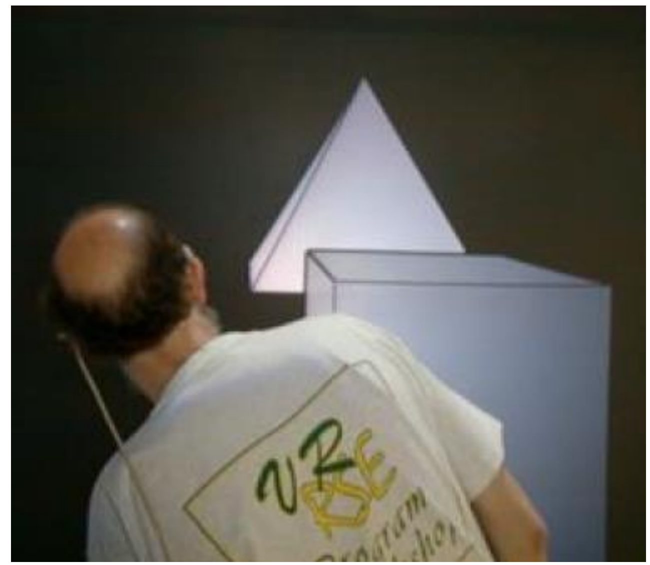
motion parallax





The Effect of Motion Parallax

Courtesy of Bill Sherman



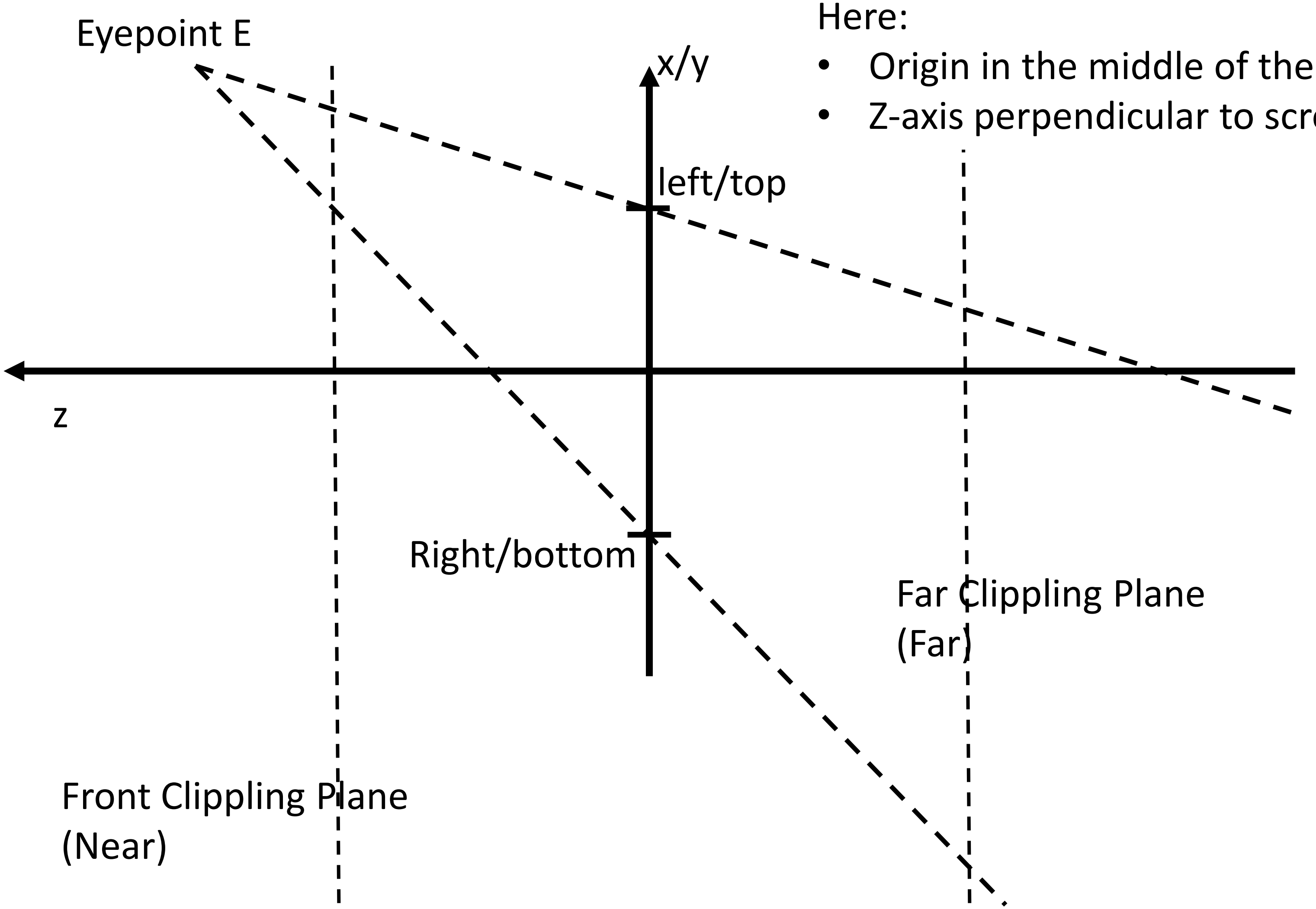
Video: Viewer Centered Projection

Video: Courtesy of VRVis, Vienna

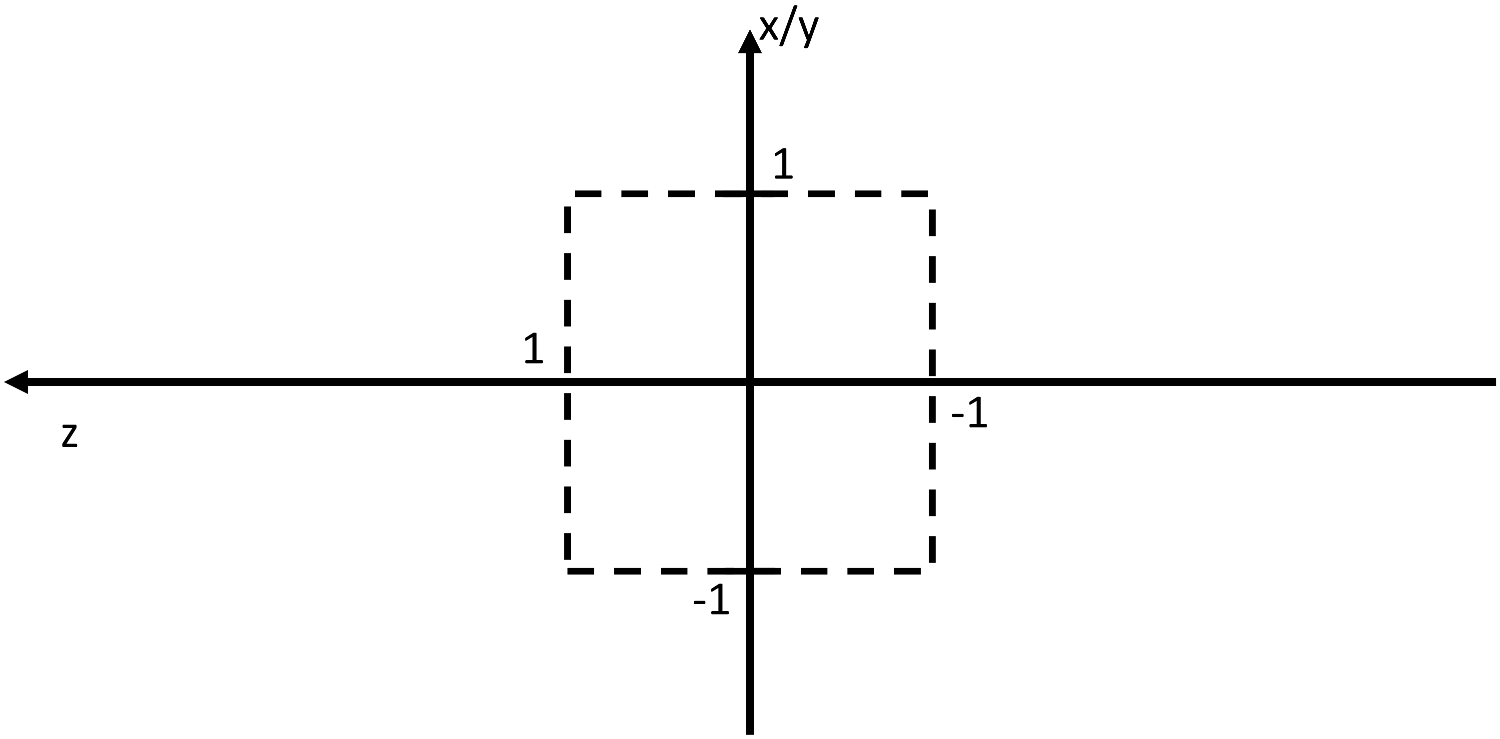
Diagonal Projection

Here:

- Origin in the middle of the screen
- Z-axis perpendicular to screen



Goal: Canonical View Volume

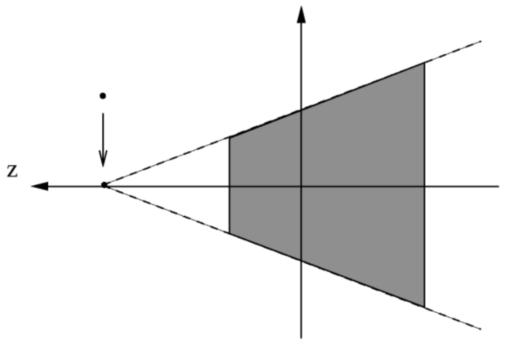


- **See Blackboard for Details**

Derivation of the Projection Matrix (I)

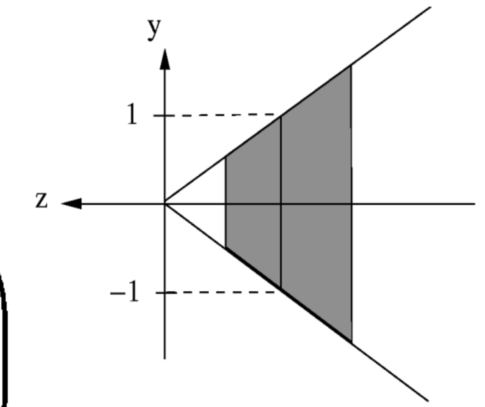
Step 1: Shearing of view volume

$$P_1 = SH_{xy}(\frac{-E_x}{E_z}, \frac{-E_y}{E_z}) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ \frac{-E_x}{E_z} & \frac{-E_y}{E_z} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$



Step 2: Translation of E to the origin

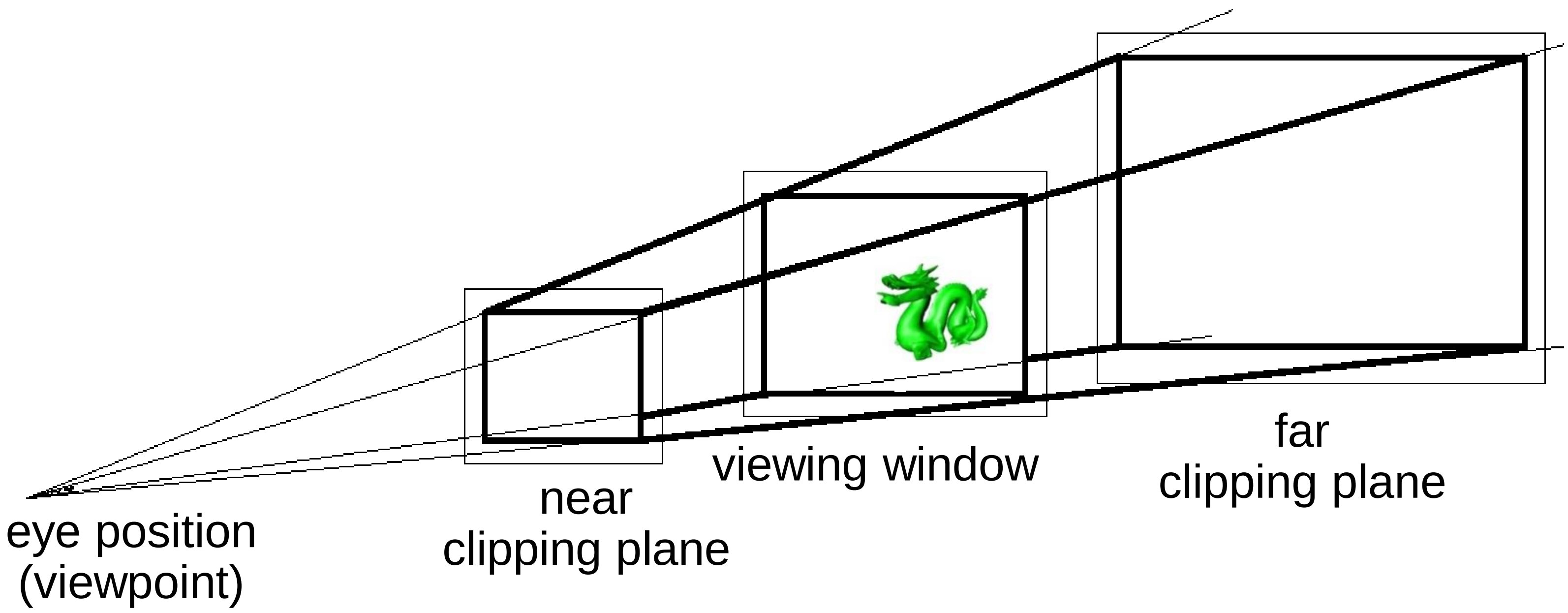
$$P_2 = T(0,0,-E_z) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -E_z & 1 \end{pmatrix}$$



Step 3: Scaling of the window to the unit rectangular

$$P_3 = S(\frac{2}{right-left}, \frac{2}{top-bottom}, 1, 1) = \begin{pmatrix} \frac{2}{right-left} & 0 & 0 & 0 \\ 0 & \frac{2}{top-bottom} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

View Volume

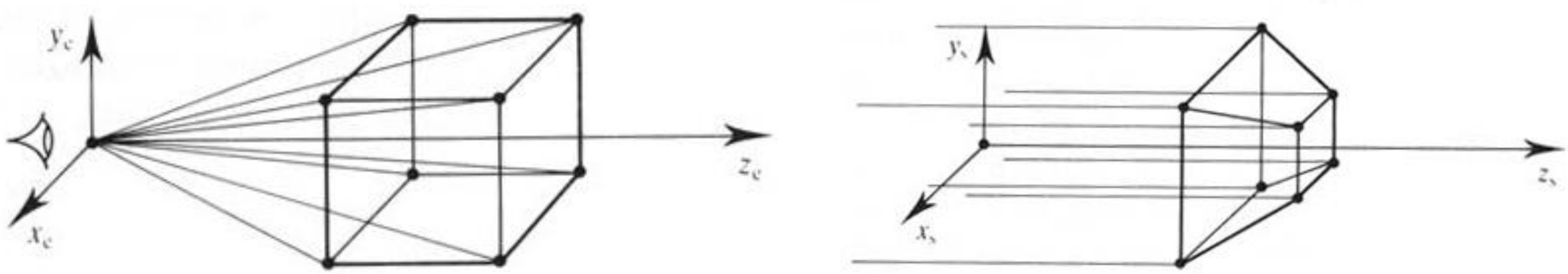


far
clipping plane
viewing window
near
clipping plane
eye position
(viewpoint)

Z-Buffering

Z-Buffer

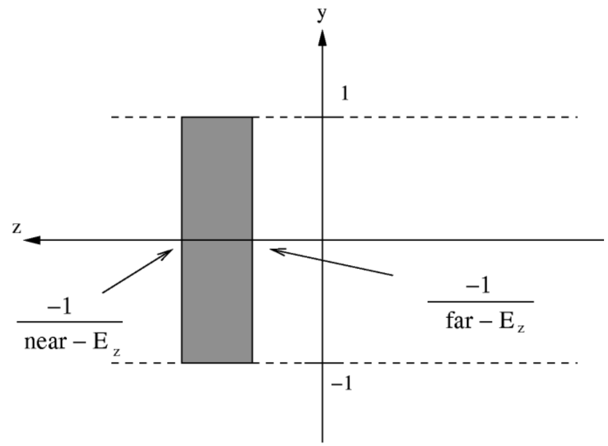
- Special memory on graphics hardware, 1 entry for every pixel
- Updated with the highest z value of 3-D object points that cover its pixel
- Accuracy depends on
  - Length of memory words („depth“) (usually 24 bits/pixel)
  - Z-value of front and back clipping plane
- Compare points lying on the same projector (OpenGL: parallel projection!)



Derivation of the Projection Matrix (II)

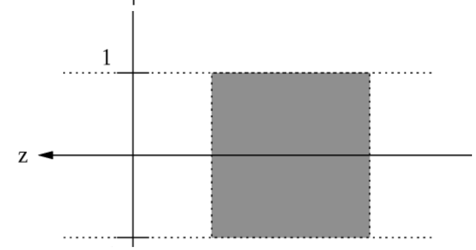
Step 4: Scaling as a function in z

$$P_4 = SZ \begin{pmatrix} E_z & 0 & 0 & 0 \\ 0 & E_z & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$



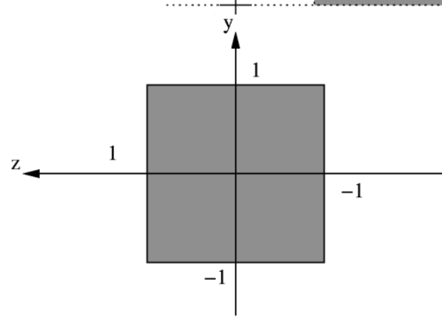
Step 5: Scaling of the view volume in z

$$P_5 = S(1, 1, \frac{2(far - E_z)(near - E_z)}{far - near}, 1)$$



Step 6: Translation in the direction of z

$$P_6 = T(0, 0, \frac{-2E_z - far - near}{far - near})$$



$$P = \prod_{i=1}^{6} P_i$$

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Parameters:

- Position of the view window: left, right, top, bottom
- Near and far clipping plane: near, far
- Eye position E

$$\mathbf{P} = \begin{pmatrix} \frac{2e_z}{r-l} & 0 & 0 & 0 \\ 0 & \frac{2e_z}{o-u} & 0 & 0 \\ \frac{-2\left(e_x - \frac{r+l}{2}\right)}{r-l} & \frac{-2\left(e_y - \frac{o+u}{2}\right)}{o-u} & \frac{2e_z-f-n}{f-n} & -1 \\ -\frac{r+l}{r-l}e_z & -\frac{o+u}{o-u}e_z & \frac{-e_z(2e_z-f-n)+2(f-e_z)(n-e_y}{f-n}) & e_z \end{pmatrix}$$

Exact correspondence
of visual perception
in the real world and in the virtual world

Virtual Reality:

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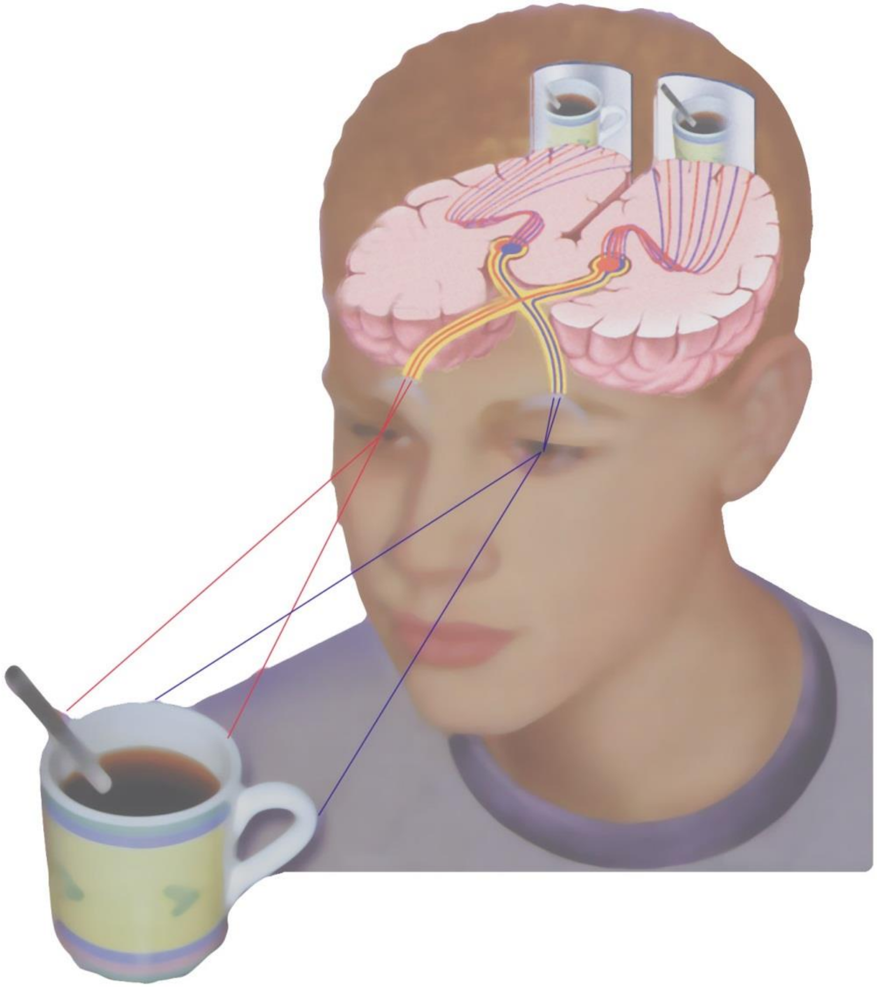

Perception of Distances in VR

Distances are typically under-estimated in virtual environments:

- **Influence candidates:**
  - Rendering Quality
    - Illumination model
    - Positions of light sources
    - Resolution / aliasing
  - Framerate
  - Display hardware characteristics / quality
    - Brightness Uniformity
    - Accomodation / Convergence

- Distance estimation „nearly“ independent from rendering /display technology
- Many contradictory studies
- No explanation for under-estimation