# Depth Perception

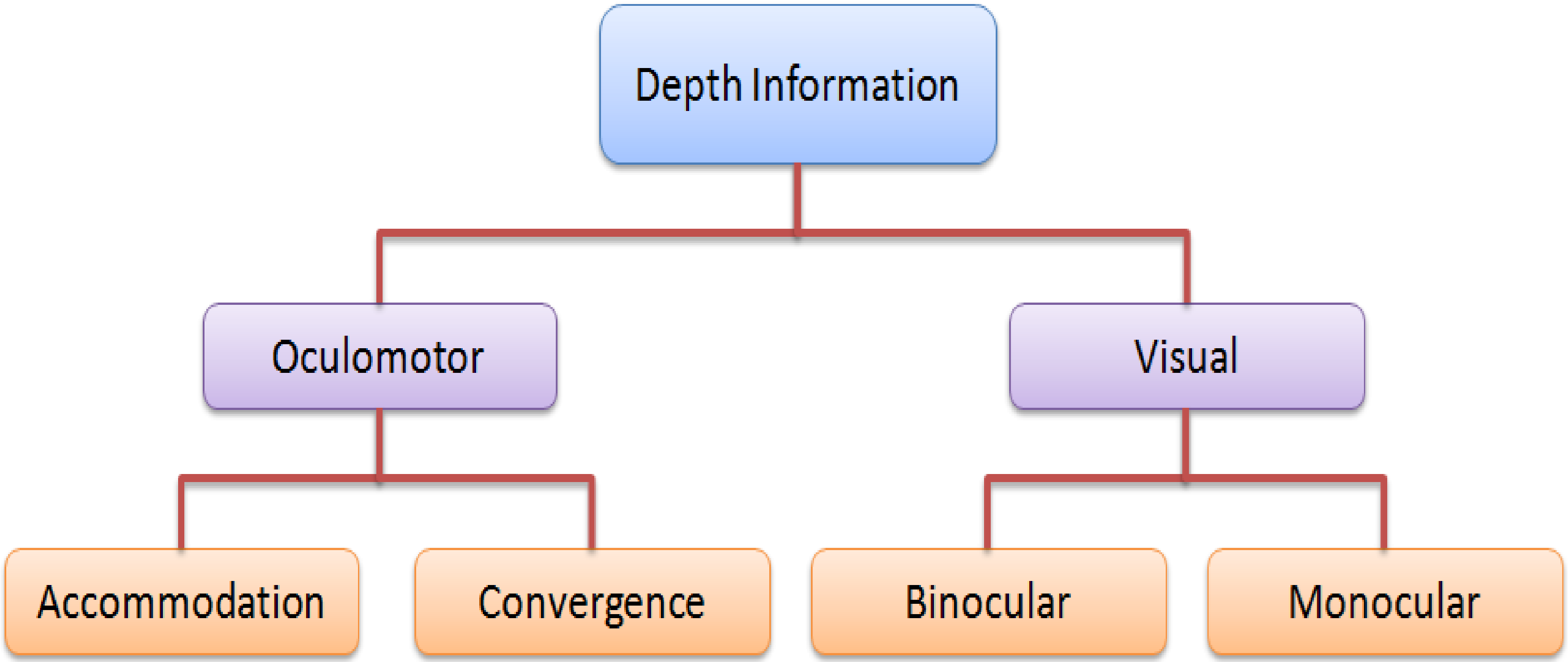
EPFL Immersive Interaction Group

# Outline

- Understanding depth
- A key monocular cue: *motion* parallax
- The main binocular cue: parallax
- Depth cues effectiveness
- Overview of stereoscopic delivery
- Conclusion

# Understanding depth

- Depth information perception:
  - Oculomotor cues: Convergence and Accommodation
  - Visual cues: Monocular and Binocular

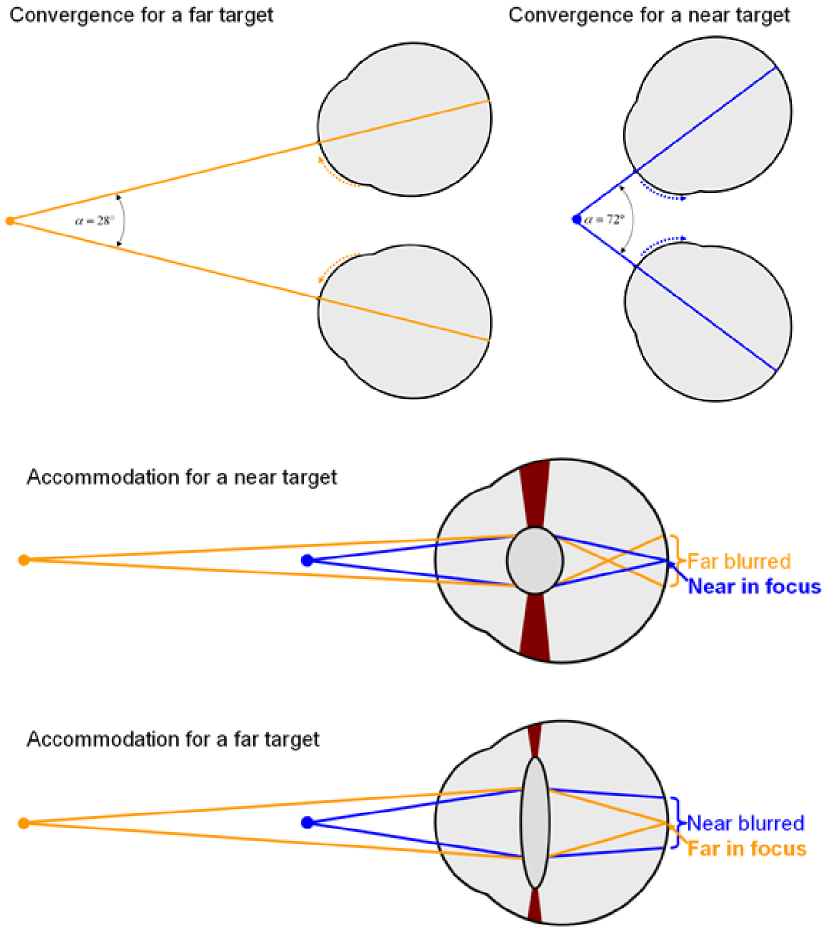


# Oculomotor cues

Accommodation and convergence allow us to see objects clearly both near and far without diplopia (double vision)

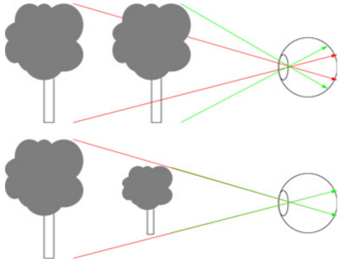
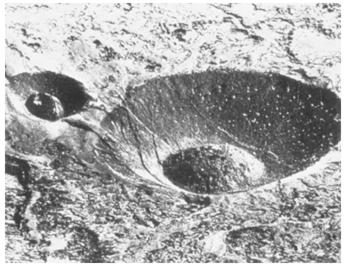
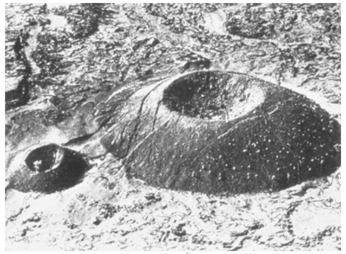
- **Convergence**: the angle formed by your eyes and the observed object. The higher the angle value is, the nearer the observed object is to your two eyes, and vice versa.

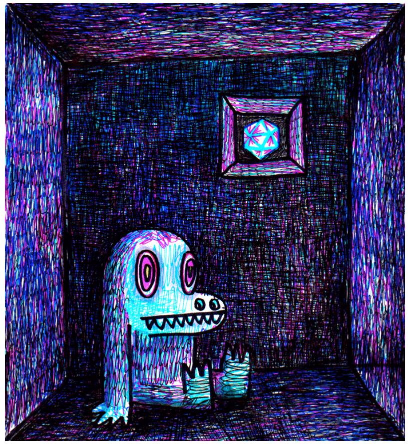
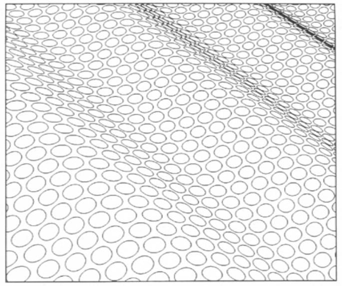
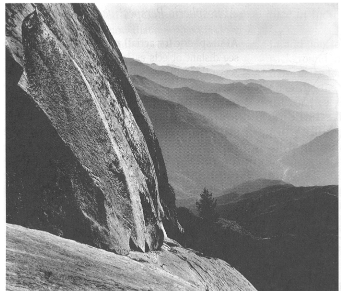
- **Accommodation**: process of changing optical power to maintain a clear image (focus) on an object as its distance varies.



# Visual cues / monocular

- Monocular cues :
  - Linear perspective
  - Relative Size
  - Texture Gradient
  - Occlusion
  - Shading
  - Tilt-shift
  - Motion Parallax
  - Atmospheric blur

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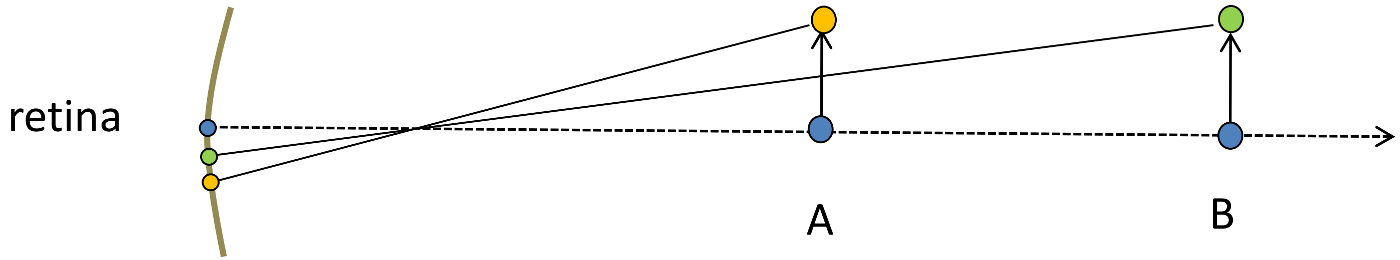
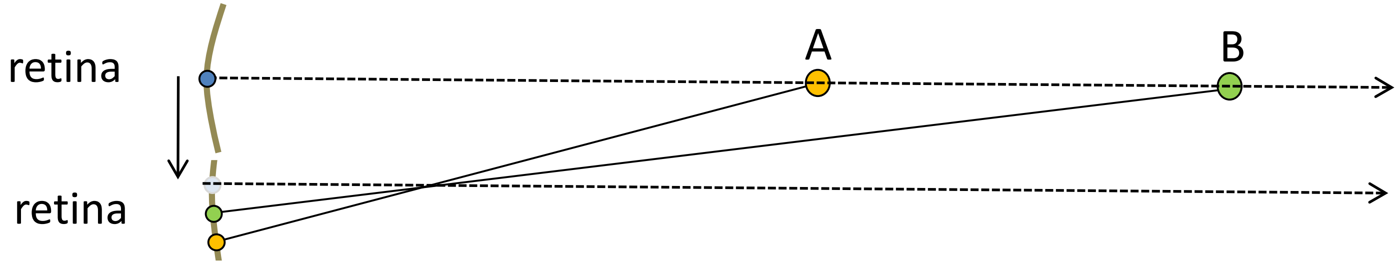
# Visual cues / monocular (2)

## Motion Parallax :

- for 2 entities with the same size, located at different depths and moving perpendicularly to the view axis , the closer one moves more on the retina than distant one.



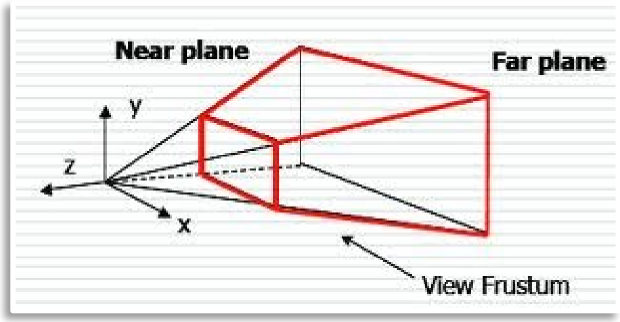

- Conversely, moving the eye in front of static entities leads to a larger movement on the retina for the closest one.



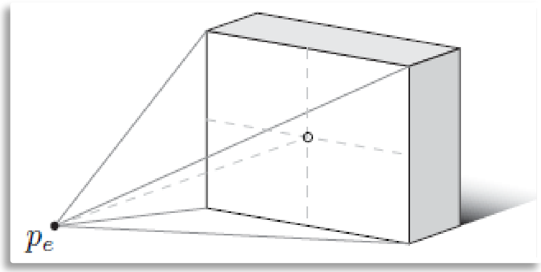

-> cheap and powerful means for providing depth cues

# What projection is needed for motion parallax ?

## The central CG perspective ?



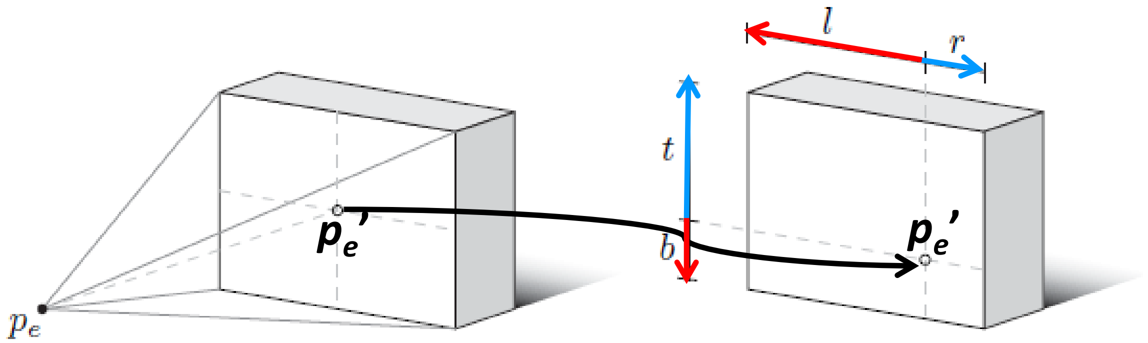

*Classical frustum volume for CG*




*If* $\boldsymbol{p_e}$ *projected on the center, a regular projection function can be used* (`gluPerspective`)

## We need to the relax the relation between the viewpoint Pe and the projection plane :

***Pe** has to be allowed to MOVE relatively to the projection plane like we can move in front of a real-world window*



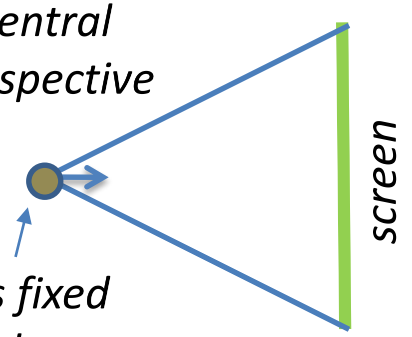

*Apex of the frustum: the* $\boldsymbol{p_e}$ *viewpoint*

*Projection of* $\boldsymbol{p_e}$ *and the 4 parameters of the frustum*

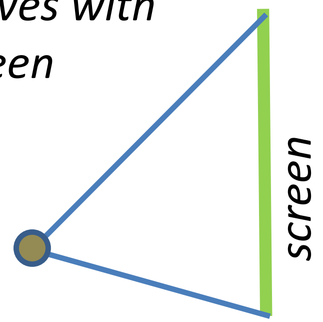
*A frustum deformation function must be used* (`glFrustum`)

# FishTank VR = motion parallax with a simple screen

- **Symmetric vs. Asymmetric perspective**
  - **Symmetric frustum**, meaning that along their view direction, they have the same Field Of View (FOV) on the left side and on the right side ***(NO motion parallax)***



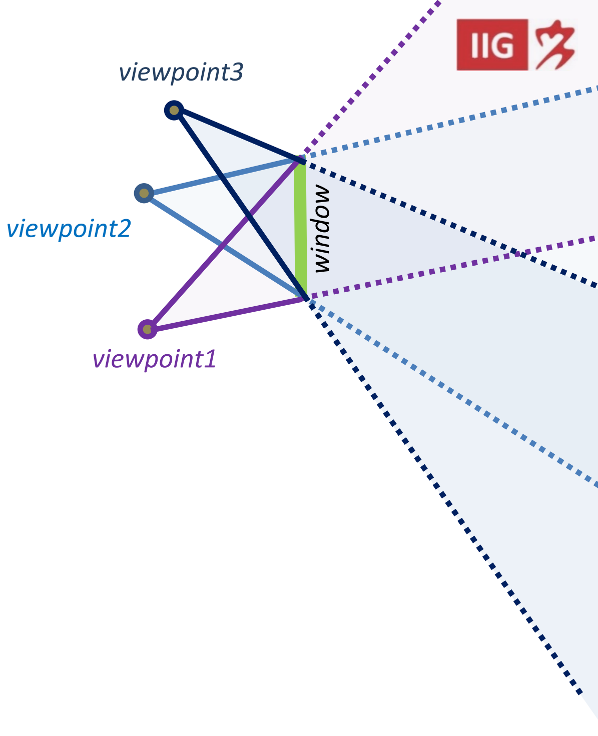

  - The **asymmetric frustum perspective** is not oriented (look through window = **FishTank VR**)




*Note: the same principle is used for the CAVE, i.e. one asymmetric projection per CAVE wall*

# FishTank VR (projection top view)

The **asymmetric frustum perspective** is not oriented ( = look through a *window*)

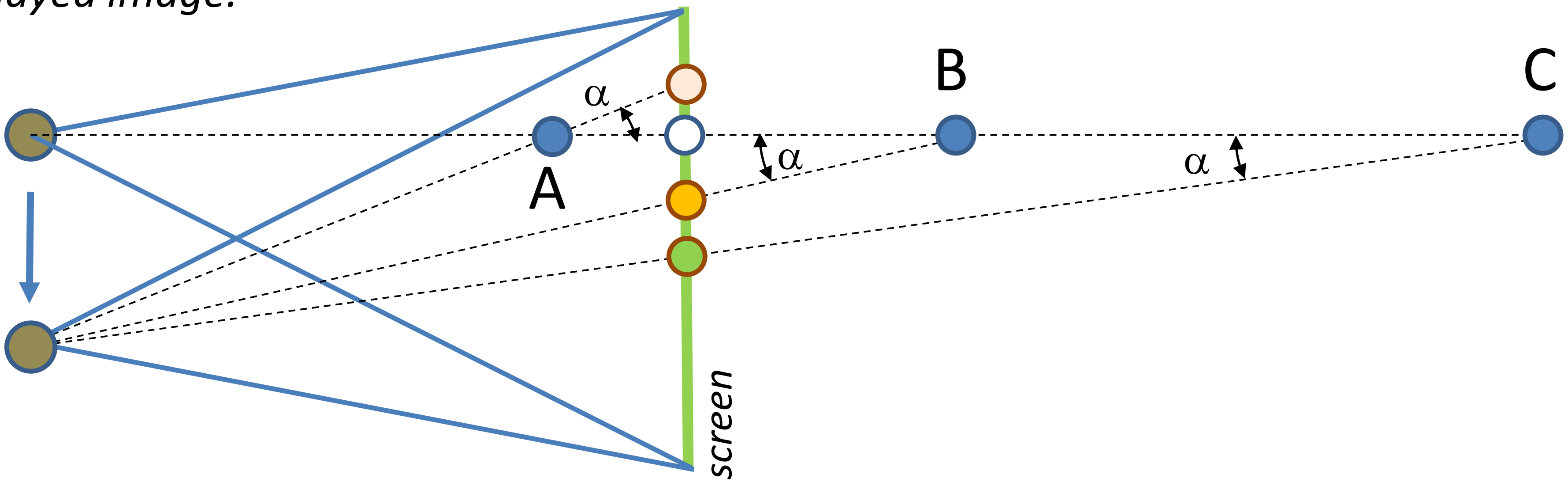



*The viewpoint has to be tracked for the relative depth effect to take place*

*The viewpoint movement relatively to the screen modifies the displayed image.*

*The virtual entitie images of A, B and C overlap on the screen*

*The image of entities virtually in front or behind the screen move in opposite direction*




*The amplitude of the image movement on the screen is proportional to the entity distance to the screen and to tg(α) ; i.e.* ***distant entities are getting out of the field of view faster than close entities***

# Example of exploiting motion parallax : Fishtank VR

Video from Henrique Galvan Debarba for the VR course (2016)

https://www.youtube.com/watch?v=6kZEjR6sLvU

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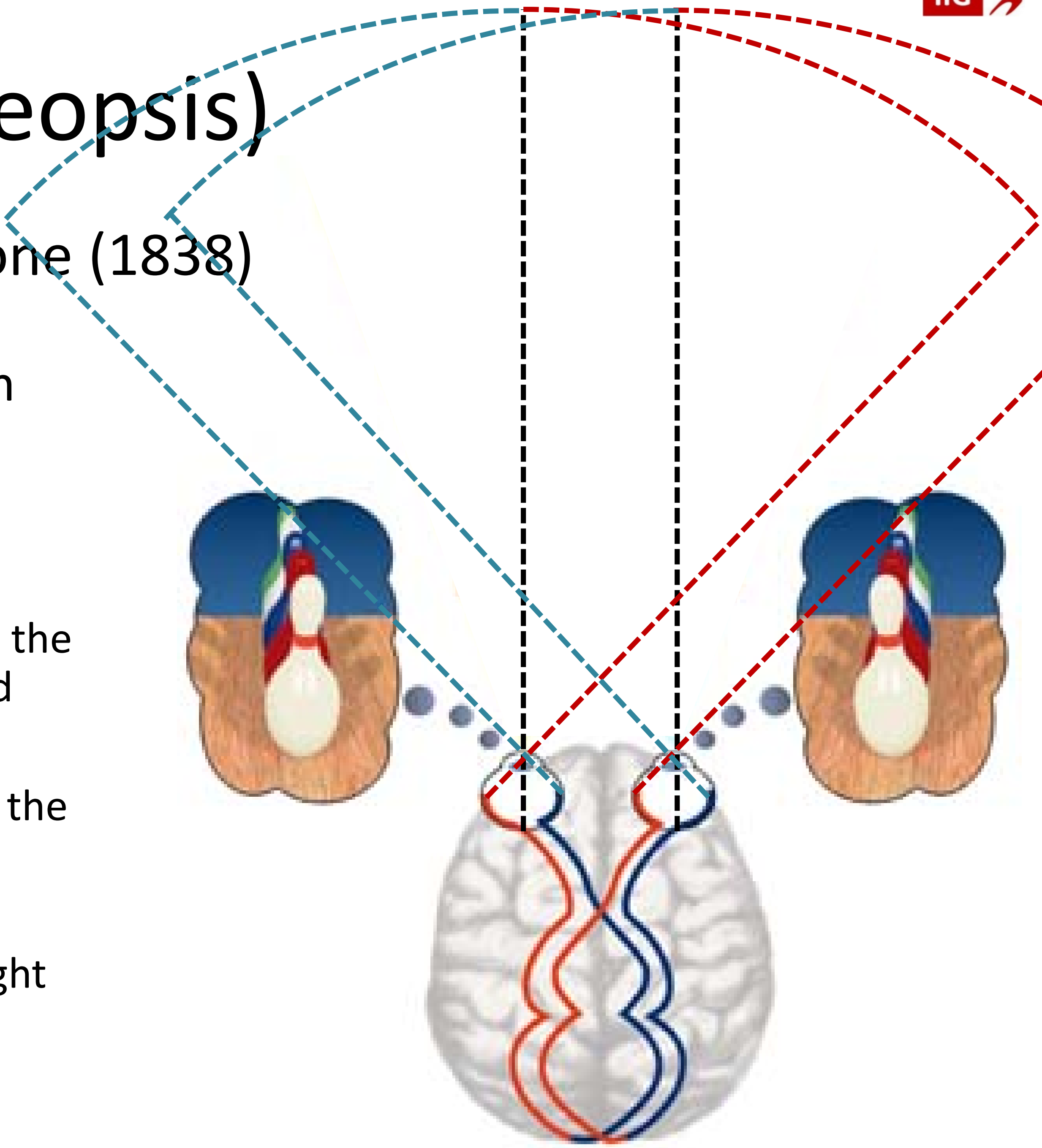
# Stereoscopic vision (stereopsis)

- Principle identified by C. Wheathstone (1838)

Two views fused in the brain = Stereovision

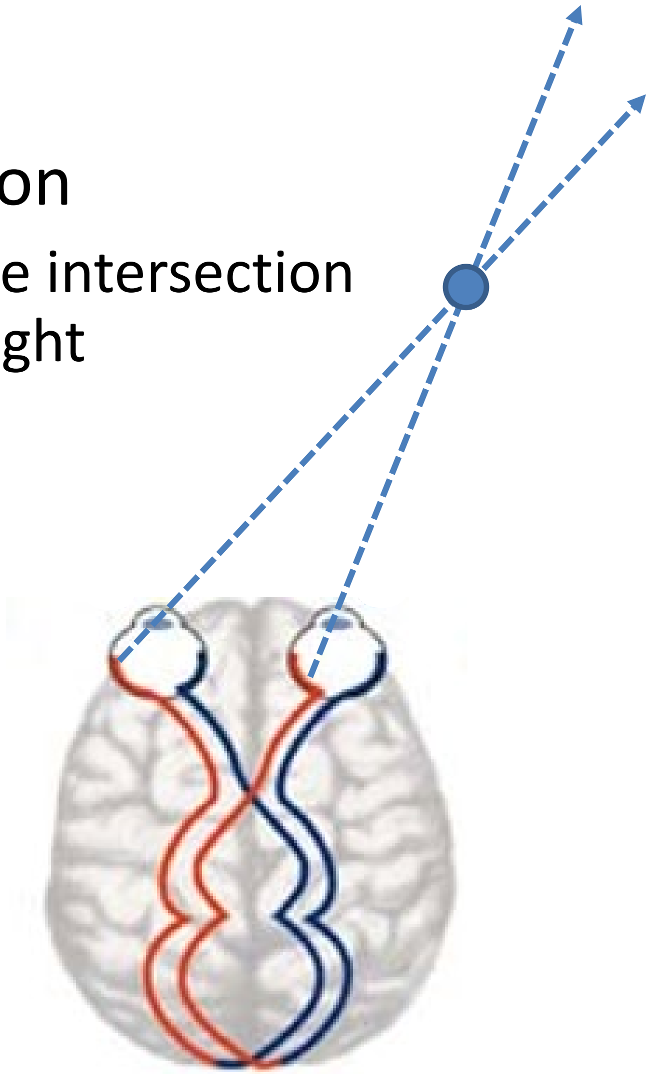
- Each eye captures its own field of view
- The two eye field of views are recombined (in the *optic chiasm*) into a **right** and a **left** visual field
- The right visual field (red pathways) is sent to the left brain hemisphere, and vice-versa.
- The small differences between the left and right source of the visual signals add up to a big difference (Depth information)



# Stereoscopic vision

Advantage of stereoscopic vision

- Offer depth information at the intersection of the left and right lines of sight



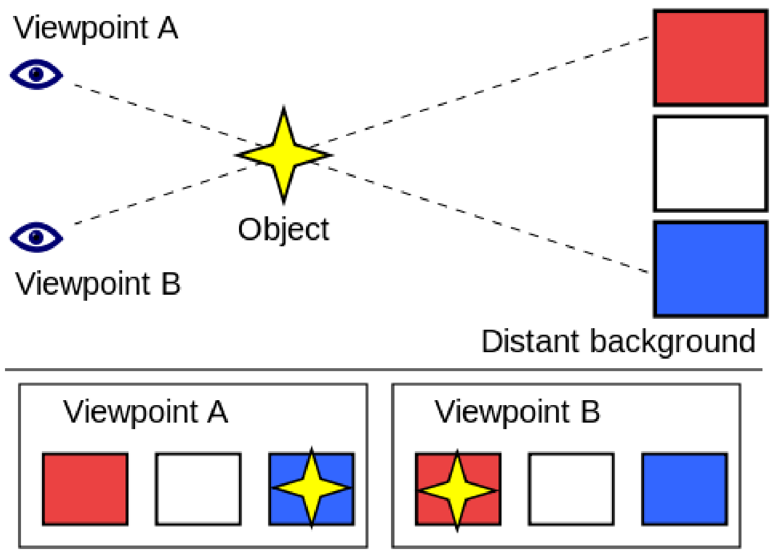
In VR, the depth information is provided by displaying different images for the right and the left eyes, matching the user's parameters (more in further slides).

# Binocular depth visual cues

**Parallax** :

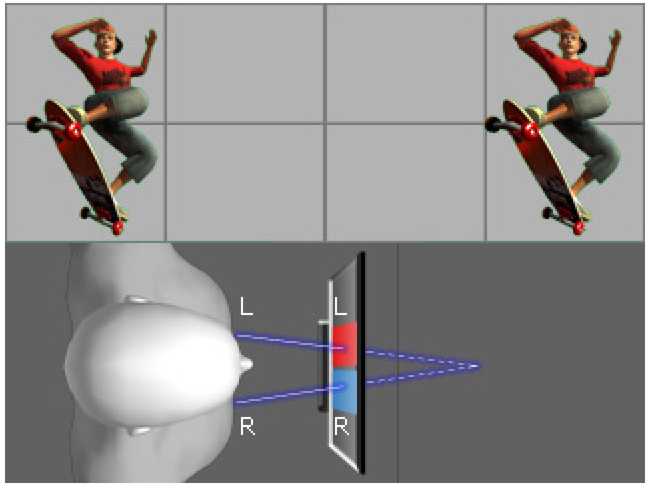
- is a displacement or *difference* (case illustrated below) in the apparent position of an object viewed along two different lines of sight

*top view*

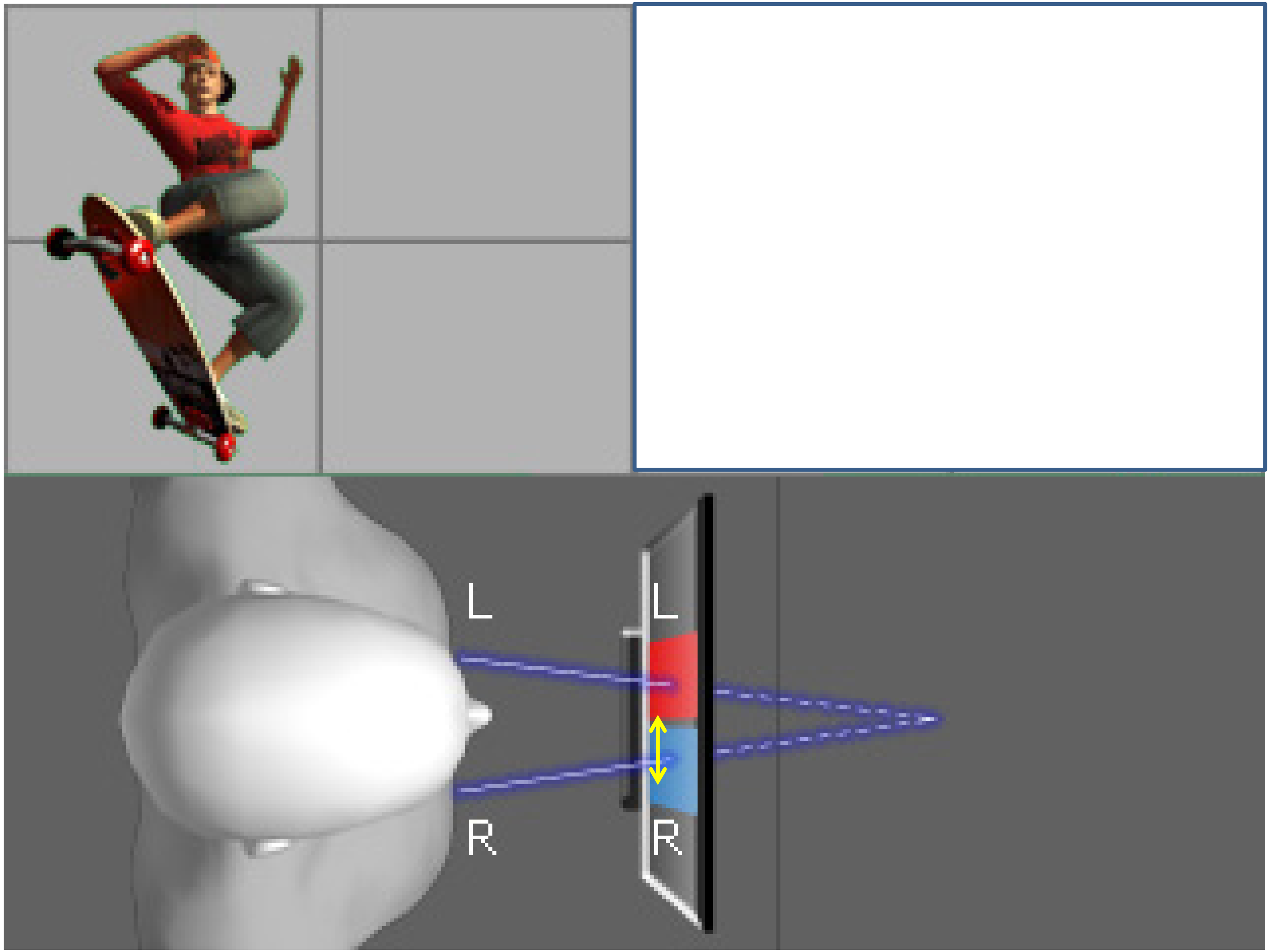


# Positive parallax

- 3 types of parallax (1:3):
  - **<u>Positive parallax</u>**: The projection for the left eye is on the left and the projection for the right eye is on the right, the distance between the left and right eye projections is called the **horizontal parallax**




Your convergence point is led to fall behind the display.

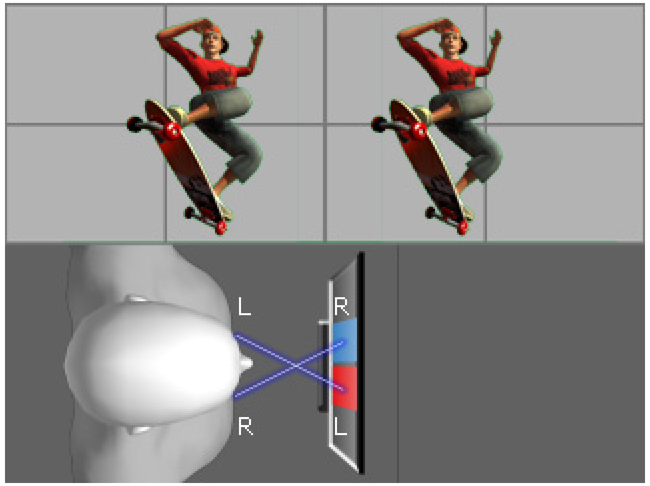


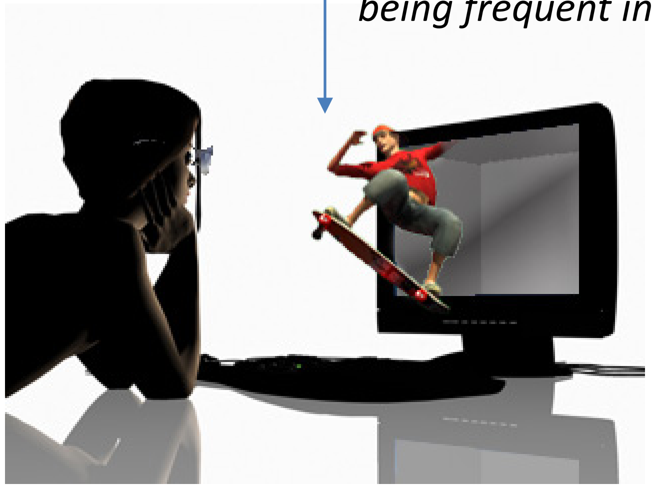

Your convergence point is led to fall behind the display.

# Negative parallax

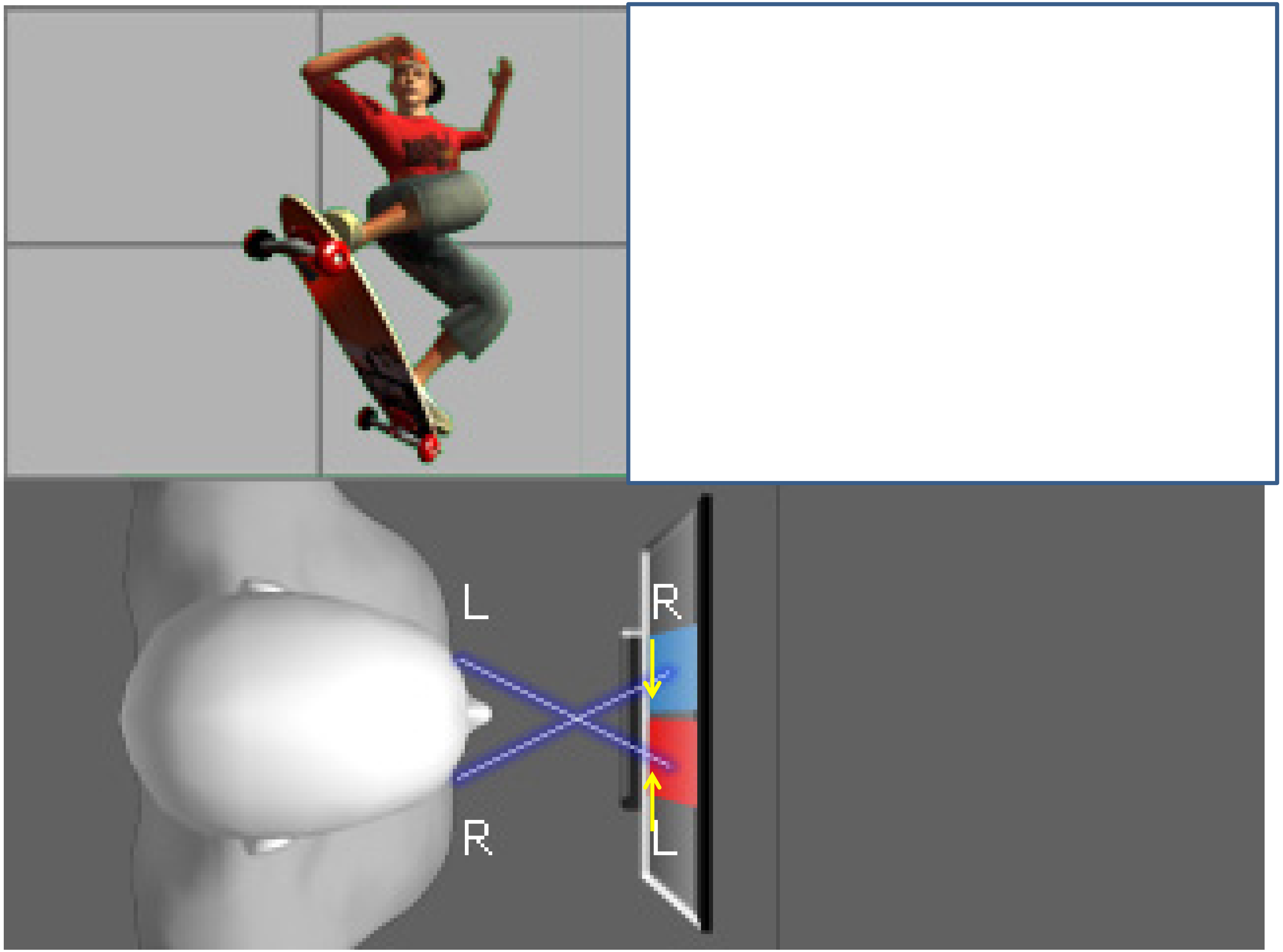
- 3 types of parallax (2:3):
  - **<u>Negative parallax</u>**: If an object is located in front of the projection plane then the projection for the left eye is on the right and the projection for the right eye is on the left.

*Please note that this type of 3rd person viewpoint is impossible in reality despite being frequent in advertisement*



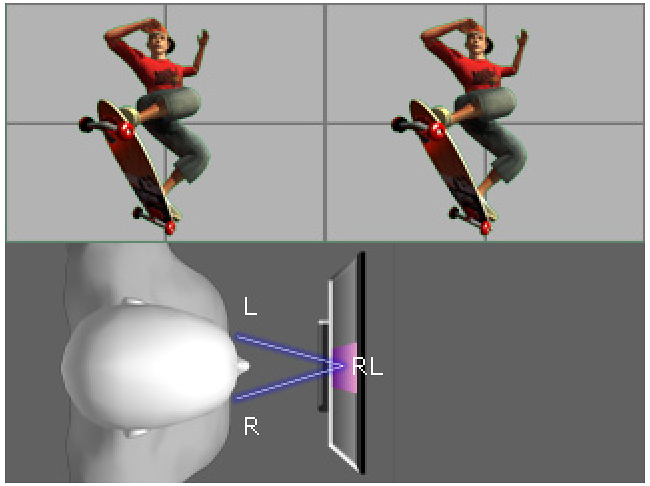
The L and R images lead your convergence point to fall in front of the display.



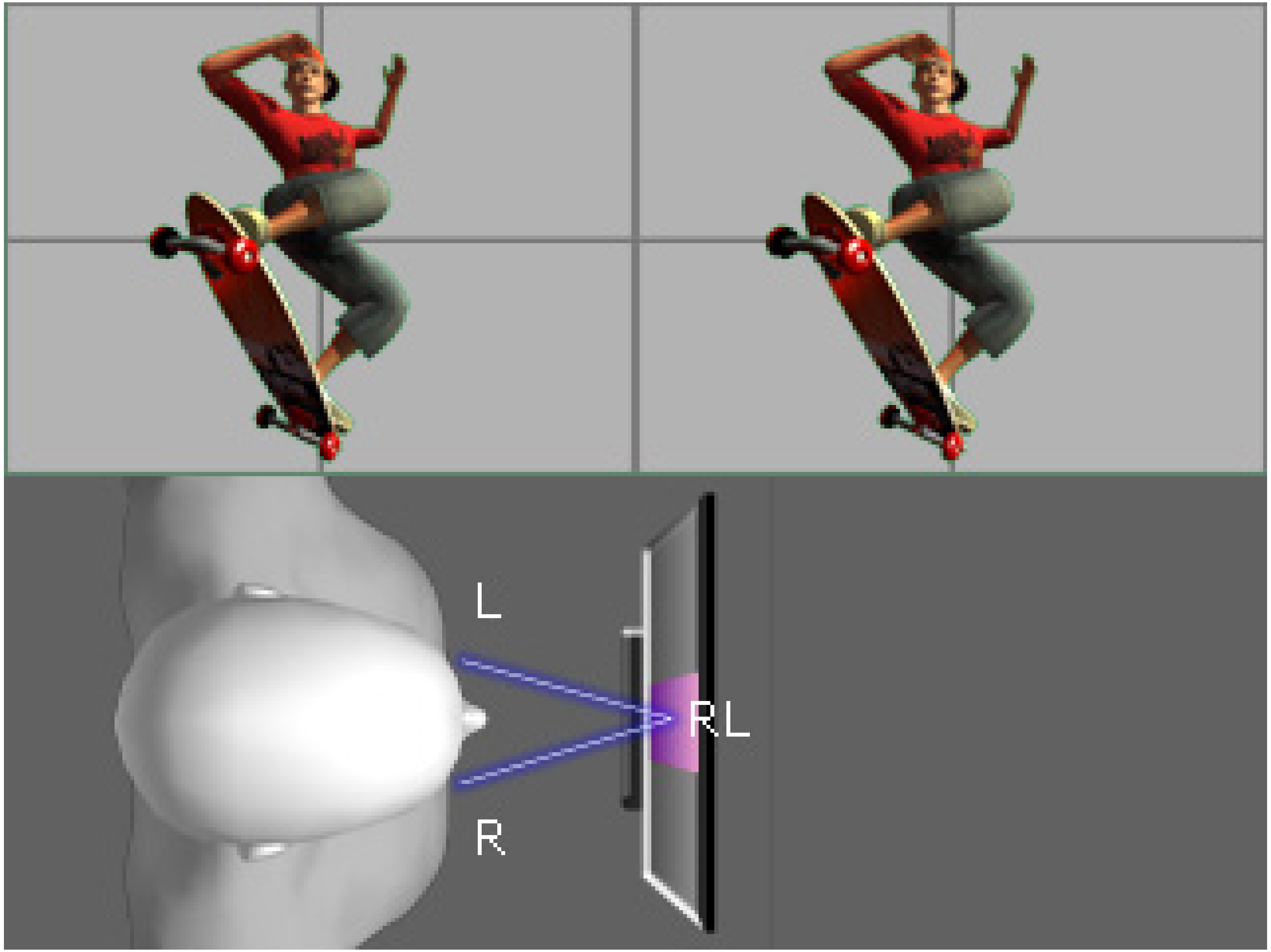

The L and R images lead your convergence point to fall in front of the display.

# Zero parallax

- 3 types of parallax (3:3):
  - **Zero parallax** : If an object lies at the projection plane then its projection onto the focal plane is coincident for both the left and right eye, hence **zero parallax**.



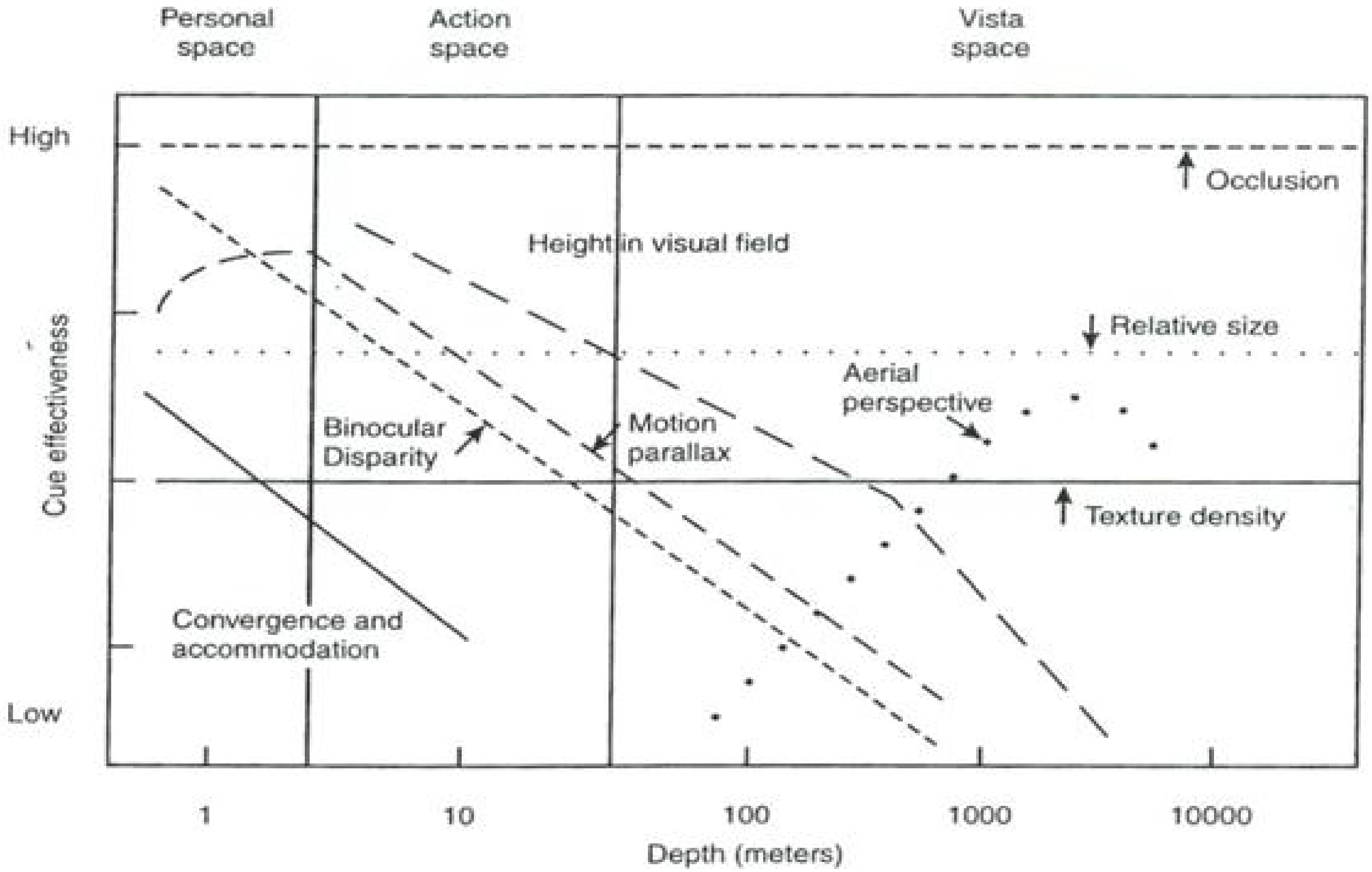

The L and R image lead your convergence point to fall on the display.




The L and R image lead your convergence point to fall on the display.

http://www.reallusion.com/iclone/Help/iClone5/Pro/09_3D_Vision/The_Concepts_of_Stereo_Vision.htm

# Depth cues effectiveness : J. Cutting and P. Vishton

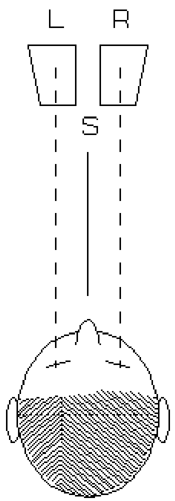


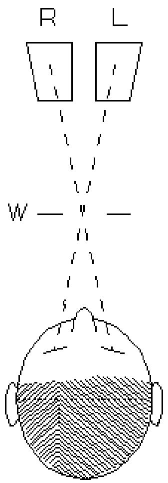
# Stereoscopic delivery

- Perceive 3D image from 2 separated images
  - Perceptual effort
    - Wall-eyed or Cross-eyed
  - Individual optics
    - HMD
  - Filtering glasses
    - Anaglyph
    - Polarization
    - Shutter

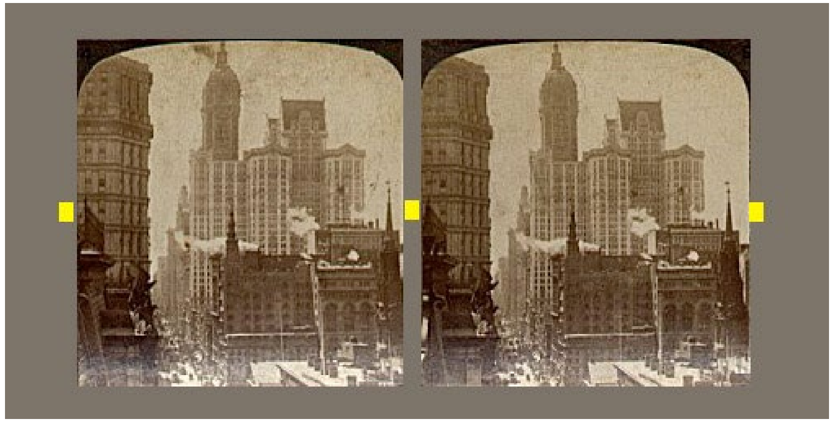
# Stereoscopic delivery: stereo pairs

- Wall-eyed or Cross-eyed



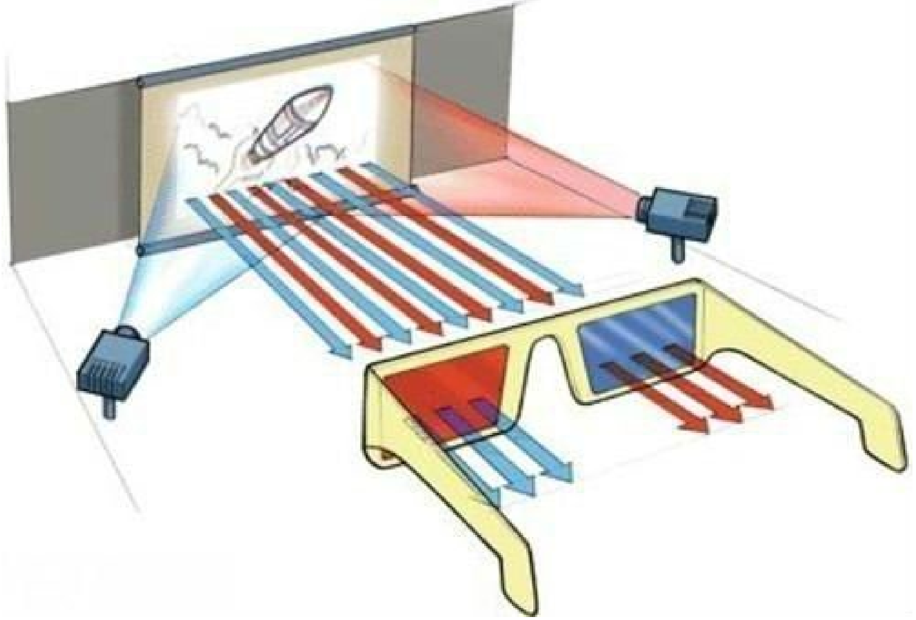

https://www.lhup.edu/~dsimanek/3d/view3d.htm



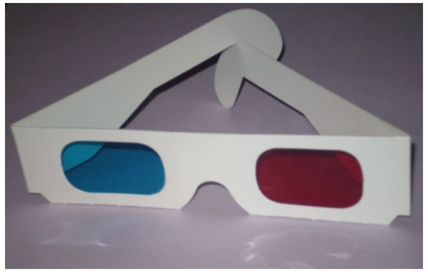
http://www.starosta.com/3dshowcase/ihelp.html

# Stereoscopic delivery: anaglyph

- Anaglyph : Photography, cinema, TV, etc..

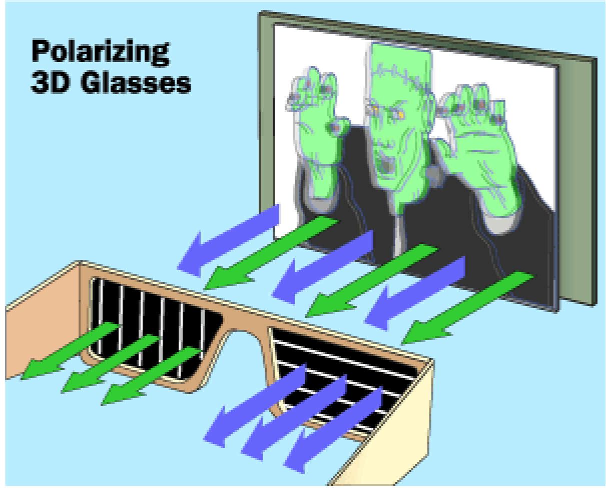


| scheme | left eye | L | R | right eye | color rendering |
|---|---|---|---|---|---|
| **red-green** | pure red | | | pure green | monochrome |
| **red-blue** | pure red | | | pure blue | monochrome |
| **red-cyan** | pure red | | | pure cyan (green+blue) | color (poor reds, good greens) |



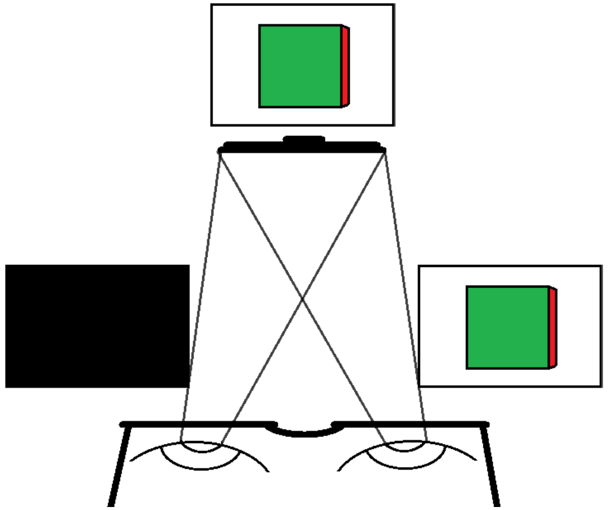
# Stereoscopic delivery: polarized glasses

- Polarized glasses (passive) : two images are projected superimposed onto the same screen or displayed through different polarizing filters.



# Stereoscopic delivery: shutter glasses

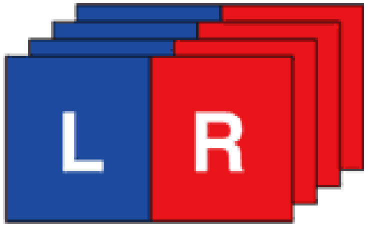
- Shutter glasses (active) :
  - presenting the image intended for the left eye while blocking the right eye's view
  - then presenting the right-eye image while blocking the left eye
  - repeating rapidly



# Stereoscopic delivery (HMD)

- Most common 3D format
  - Side by side :

    - halving the horizontal resolution of videos to store left and right eye images in each frame



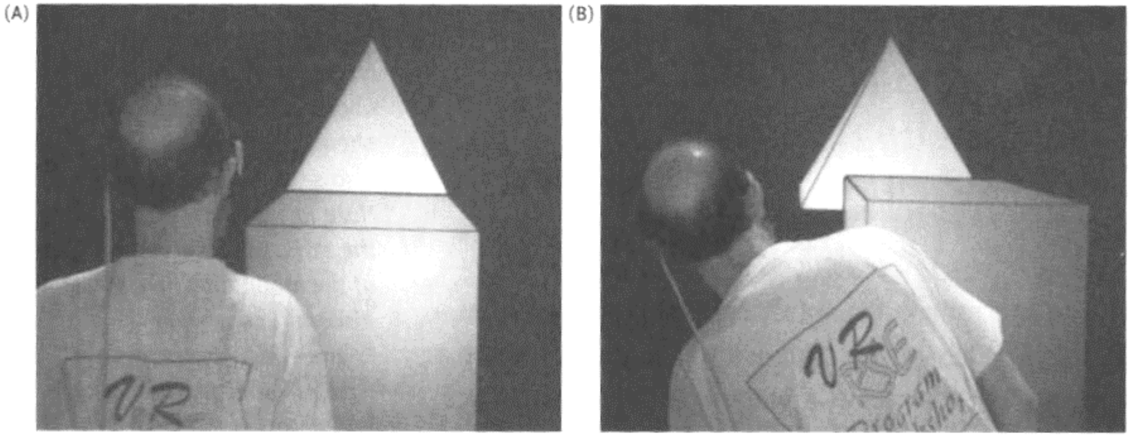

    - Provide full frame rate at the cost of image resolution

*Technical details of Head-Mounted Display are reviewed in the VR system course*

# Conclusion

Stereopsis is only one means among many others to achieve depth perception.
True stereopsis requests providing one image per eye (double computational cost compared to standard CG)

A powerful alternative at a cheaper cost is *motion parallax* as it requires a single image
+ viewpoint tracking.




Depth is obtained through the viewpoint movement

[ from R. Lindeman]