Stereoscopic media

Digital Visual Effects

Yung-Yu Chuang

3D is hot today

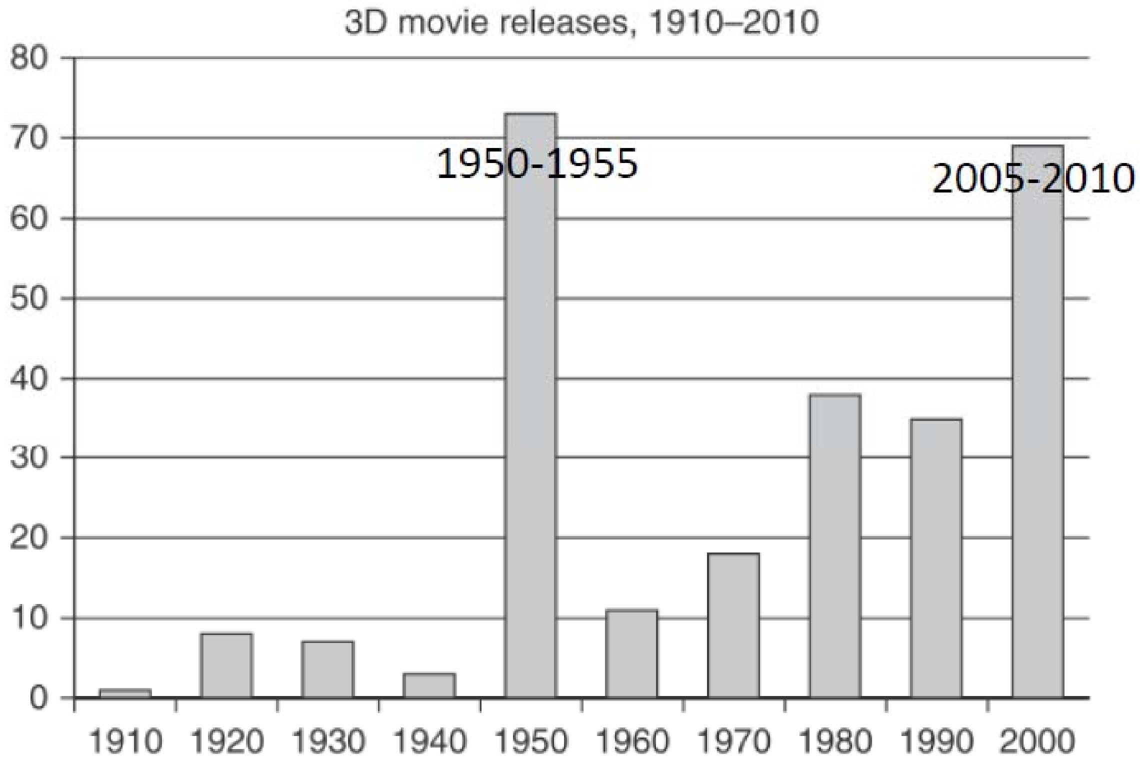
3D has a long history

- 1830s, stereoscope
- 1920s, first 3D film, *The Power of Love* projected dual-strip in the red/green anaglyph format
- 1920s, teleview system

Teleview was the earliest alternate-frame sequencing form of film projection. Through the use of two interlocked projectors, alternating left/right frames were projected one after another in rapid succession. Synchronized viewers attached to the arm-rests of the seats in the theater open and closed at the same time, and took advantage of the viewer's persistence of vision, thereby creating a true stereoscopic image.

3D has a long history

- 1950s, the "golden era" of 3-D
- The attempts failed because immature technology results in viewer discomfort.
- 1980s, rebirth of 3D, IMAX



Why could 3D be successful today?

- It finally takes off until digital processing makes 3D films both easier to shoot and watch.
- New technology for more comfortable viewing experiences
  - Accurately-adjustable 3D camera rigs
  - Digital processing and post-shooting rectification
  - Digital projectors for accurate positioning
  - Polarized screen to reduce cross-talk

3D TVs

Computers

Notebooks

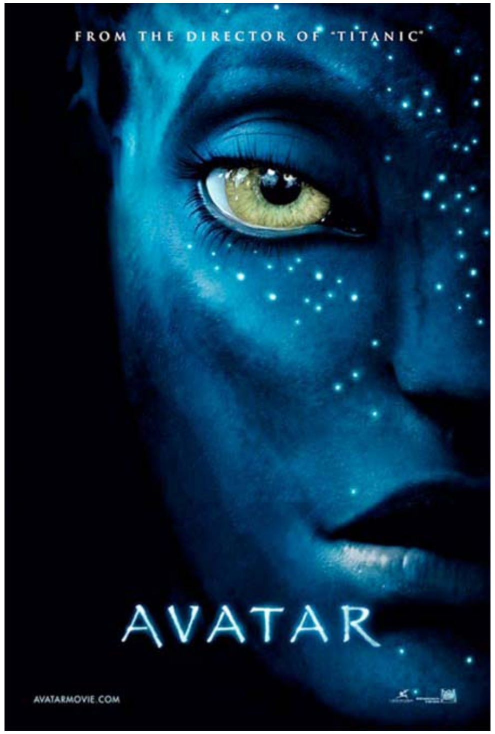
Game consoles

HTC EVO 3D


htc
10:08 AM
10
08
Seattle
Mostly Sunny
Tue, Mar 22
50°
Tips
Messages
Mail
Phone
htc
3D
dcfever.com

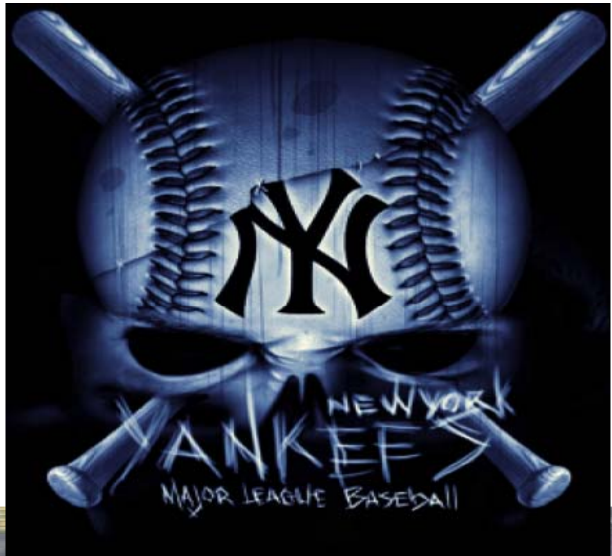
3D contents (games)

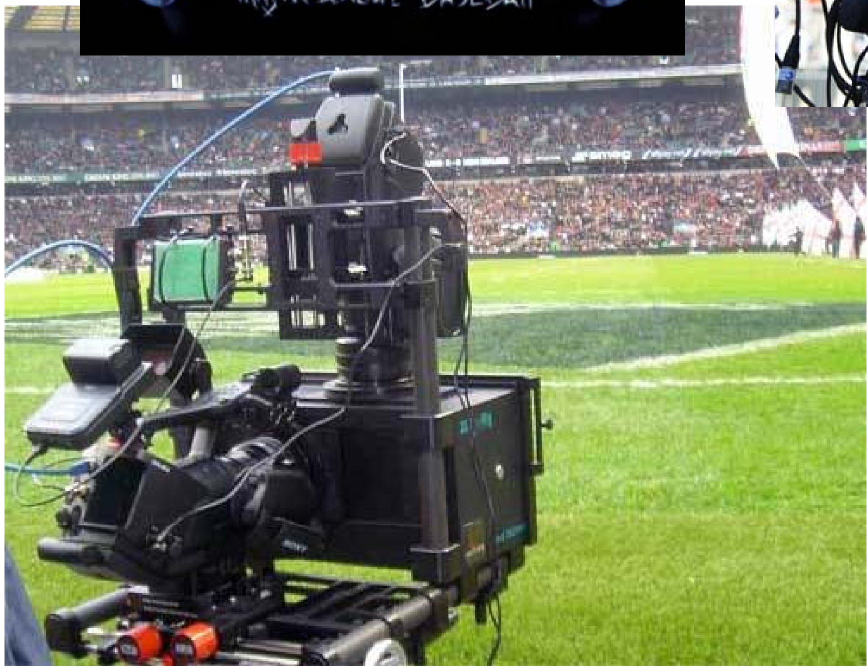
3D contents (films)



3D contents (broadcasting)

DigiVFX





3D cameras

Sony HDR-TD10E

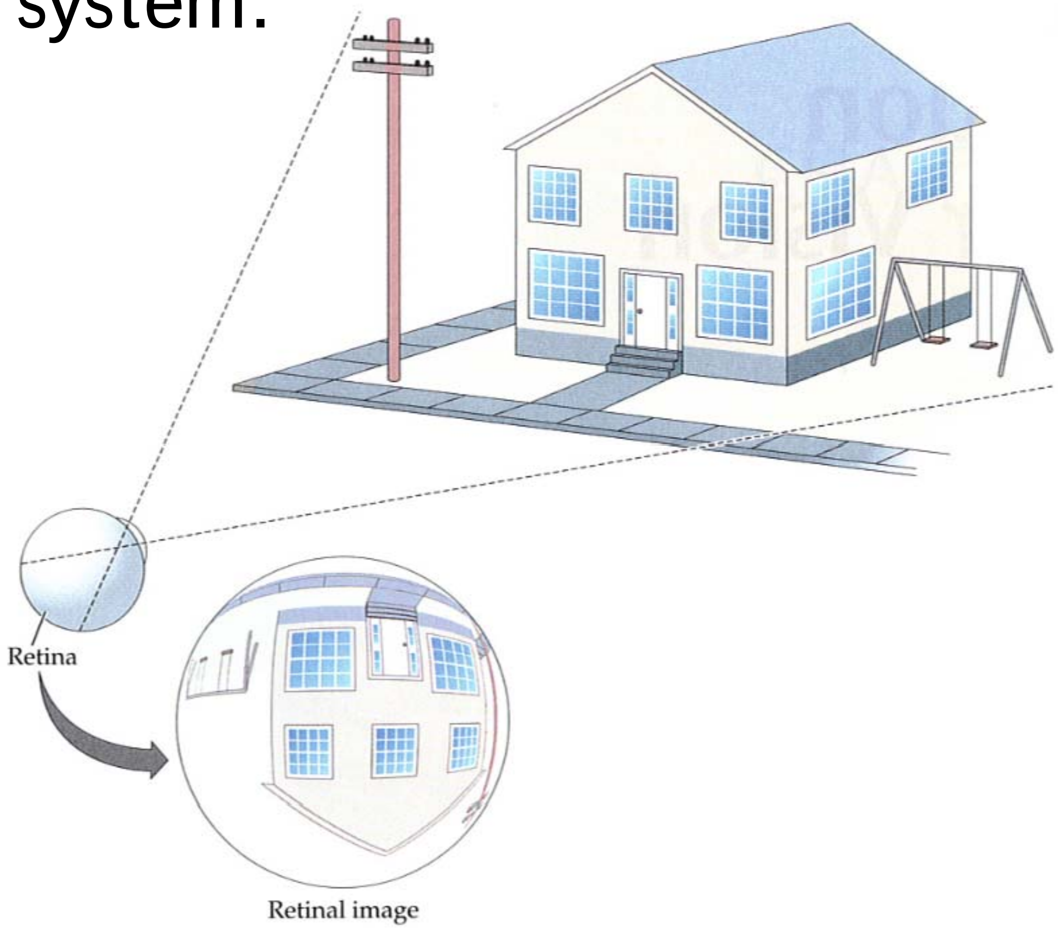
Outline

- Human depth perception
- 3D displays
- 3D cinematography
- Stereoscopic media postprocessing

Human depth perception

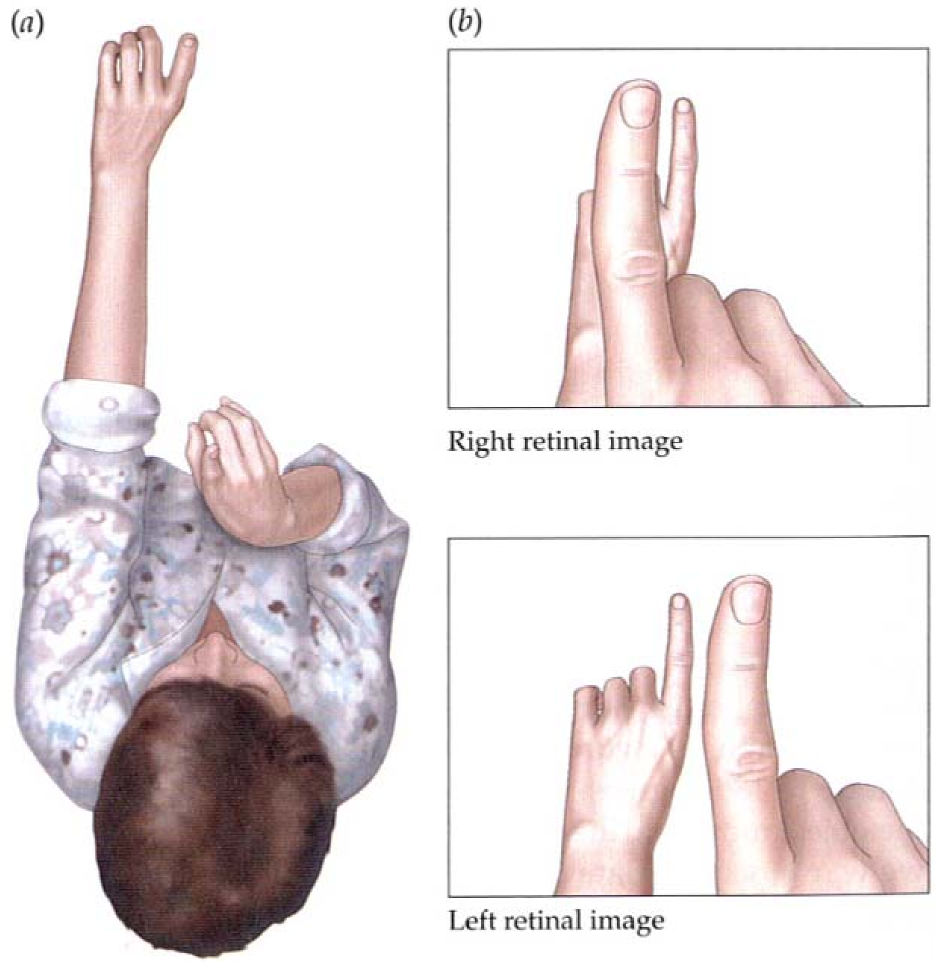
Space perception

- The ability to perceive and interact with the structure of space is one of the fundamental goals of the visual system.



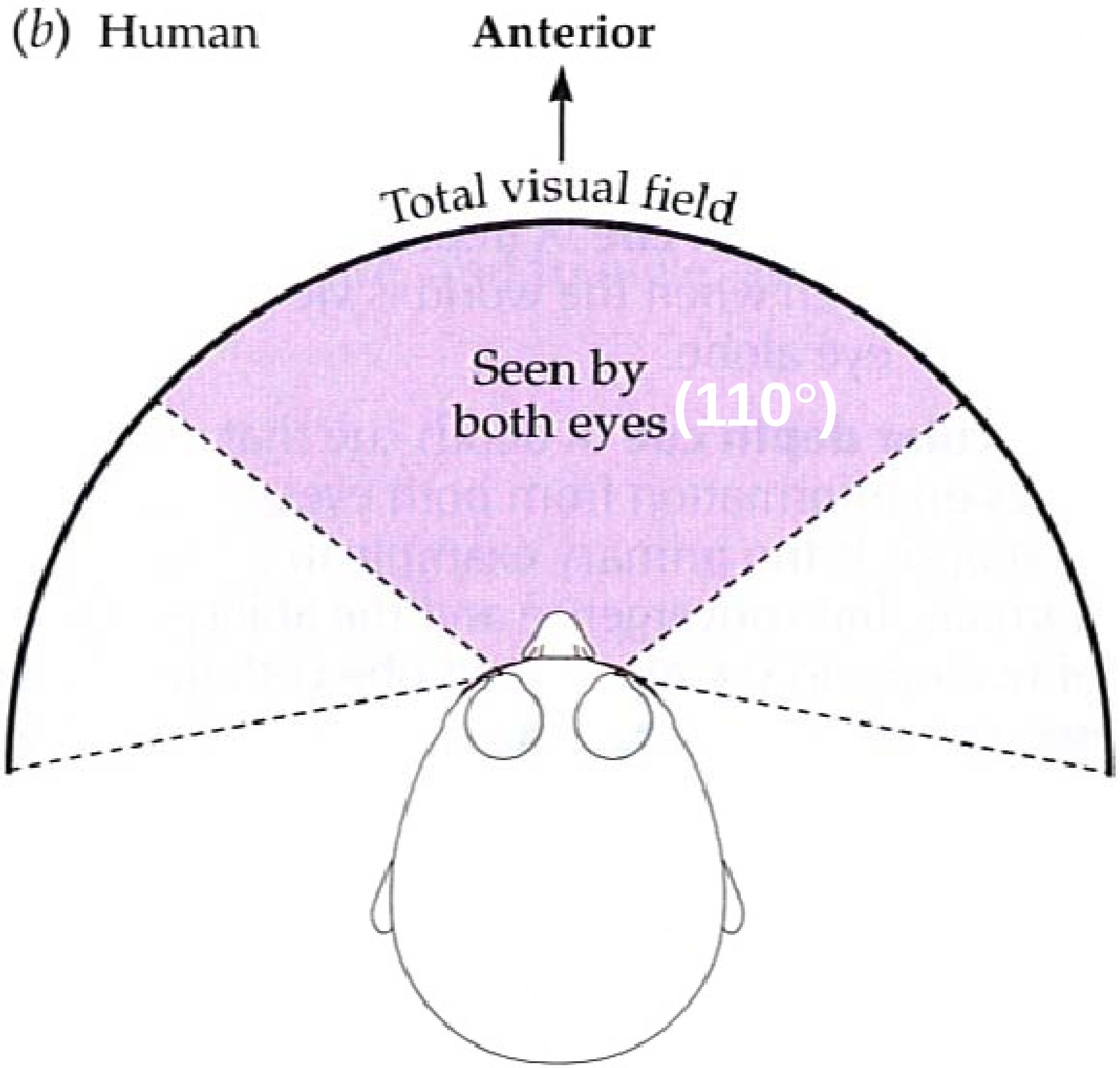
Binocular vision

- Two retinal images are different because the retinas are in slightly different places.
- The combination of signals from each eye makes performance on many tasks better with both eyes than with either eye alone.



Binocular vision

DigiVFX



Binocular disparity

- **Binocular disparity**: the differences between the two retinal images of the same scene.
- **Monocular**: with one eye
- **Stereopsis**: the ability to use binocular disparity as a cue to depth.

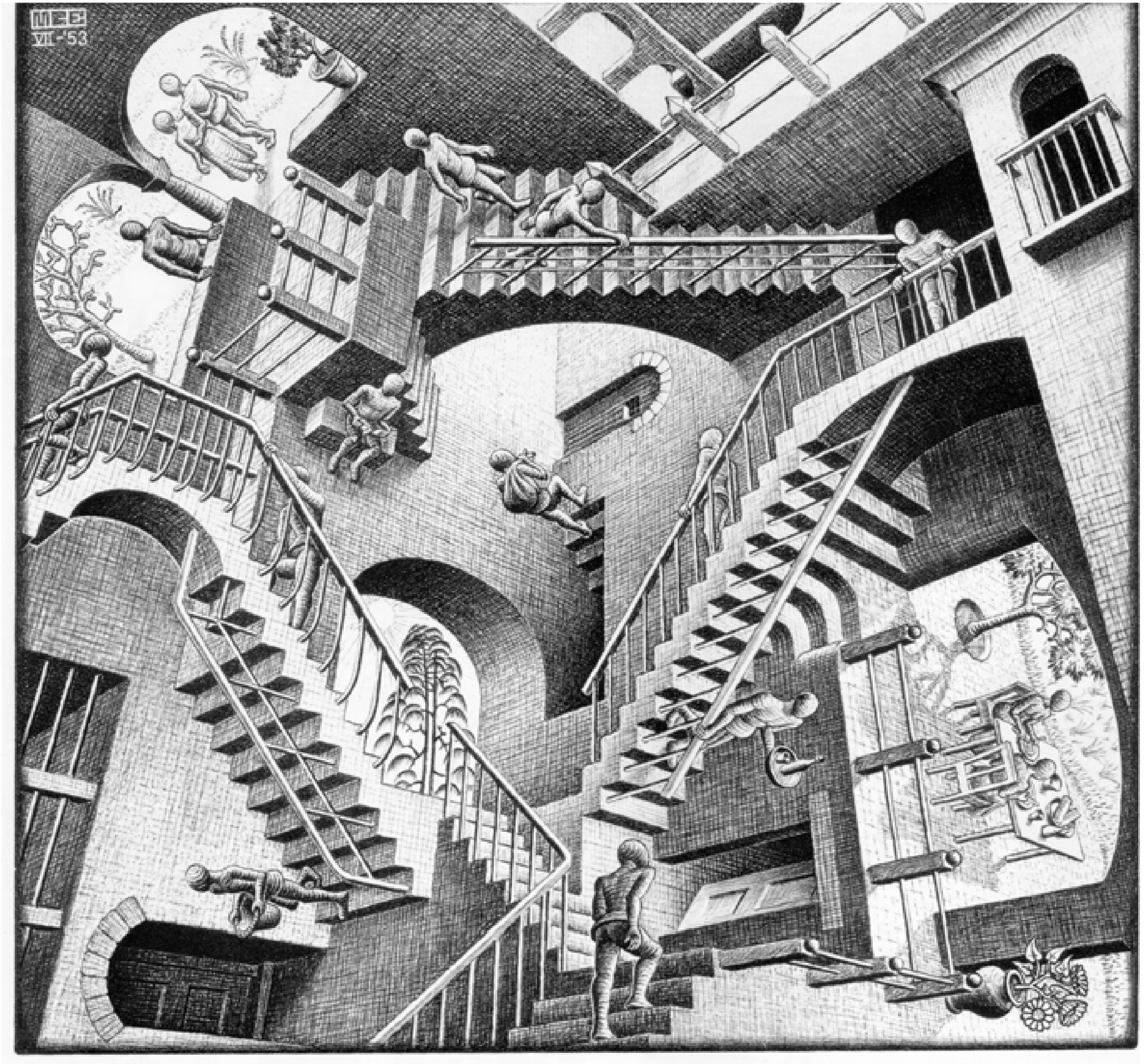
- Note that, although stereopsis adds richness to depth perception, it is not a necessary condition for depth perception. Example: rabbits and 2D films.

Monocular cues to 3D space

- Every view of the world provides multiple depth cues.
- Usually, the cues reinforce each other, combining to produce a convincing and reliable representation of 3D world.
- Occasionally, however, the cues are contradictory.

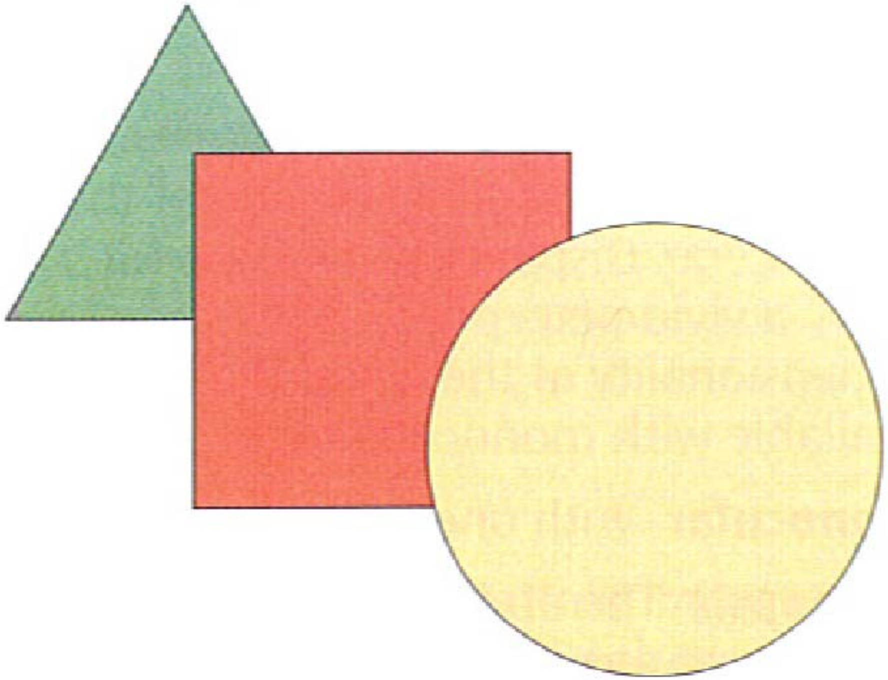
- Escher fools us by deliberately manipulating depth cues and other visual inferences. He arranges sensible local cues into a globally impossible story.

Monocular cues to 3D space

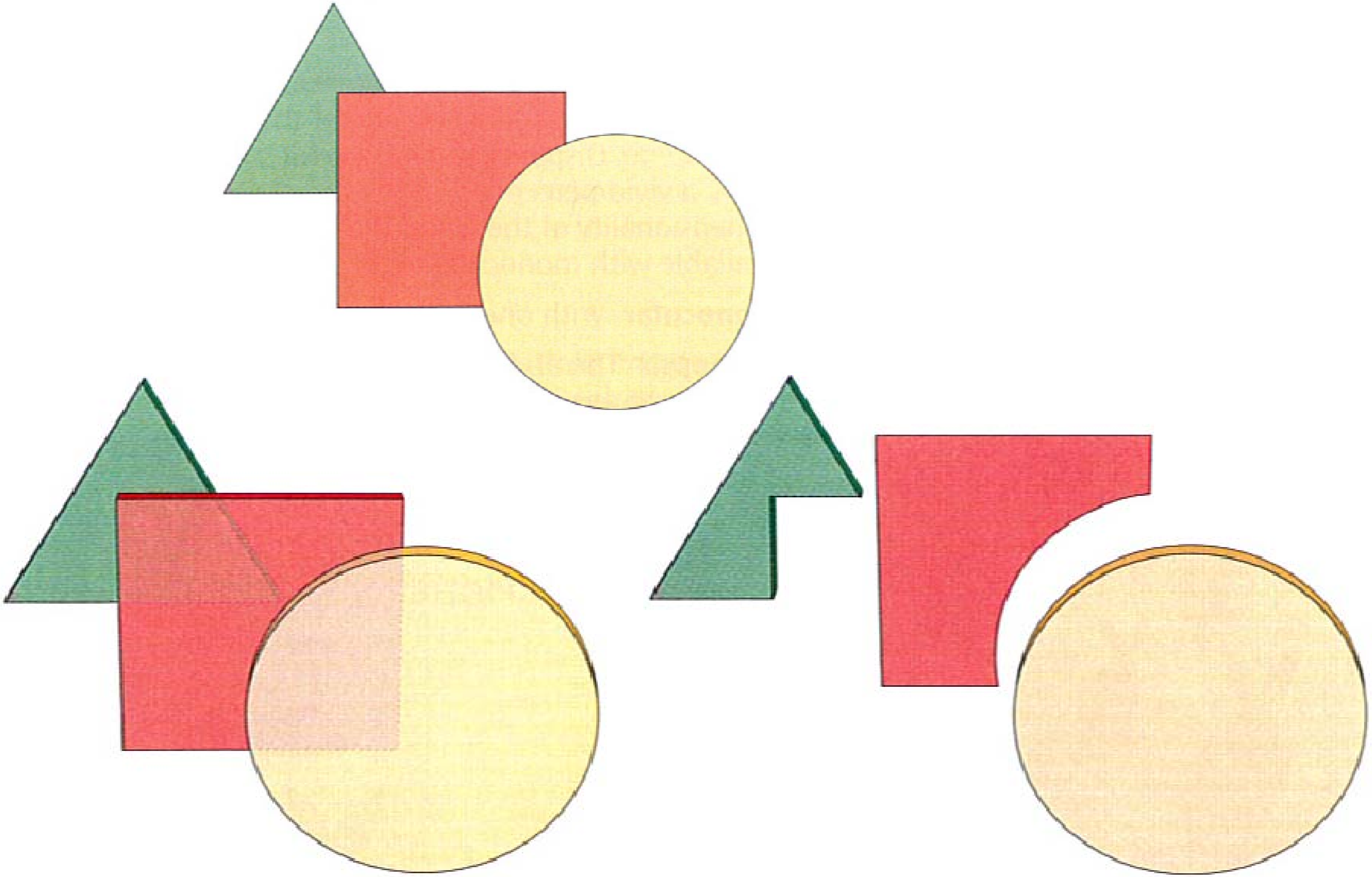


Occlusion

- Occlusion gives relative position of objects as a depth cue.
- It occurs in almost every scene and some argues that it is the most reliable depth cue.

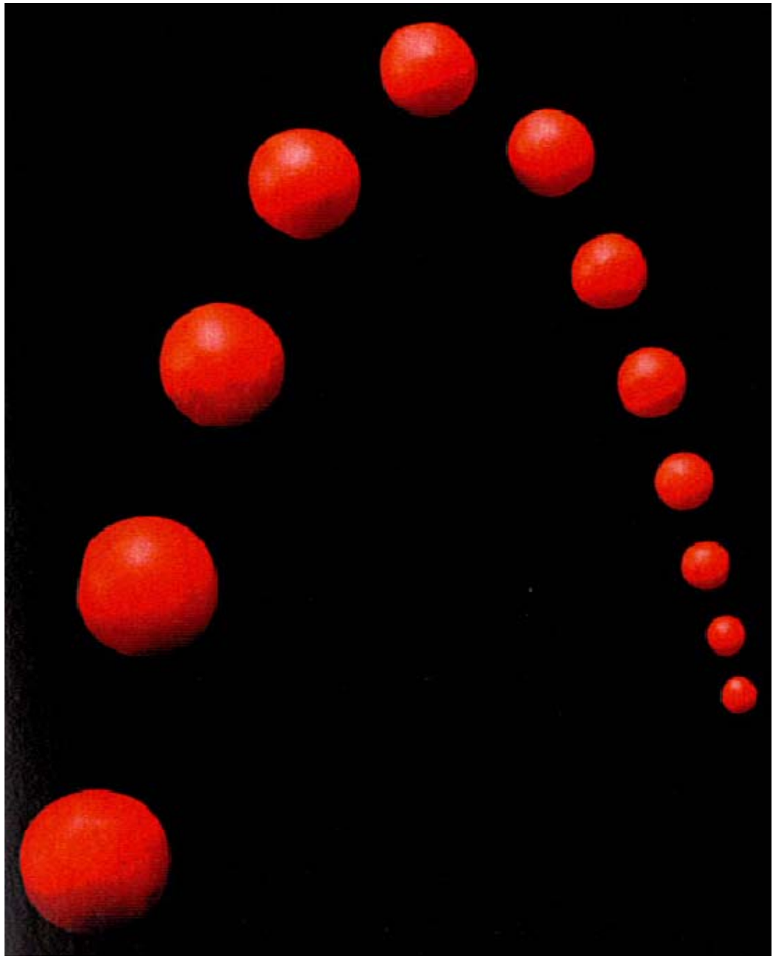


Occlusion

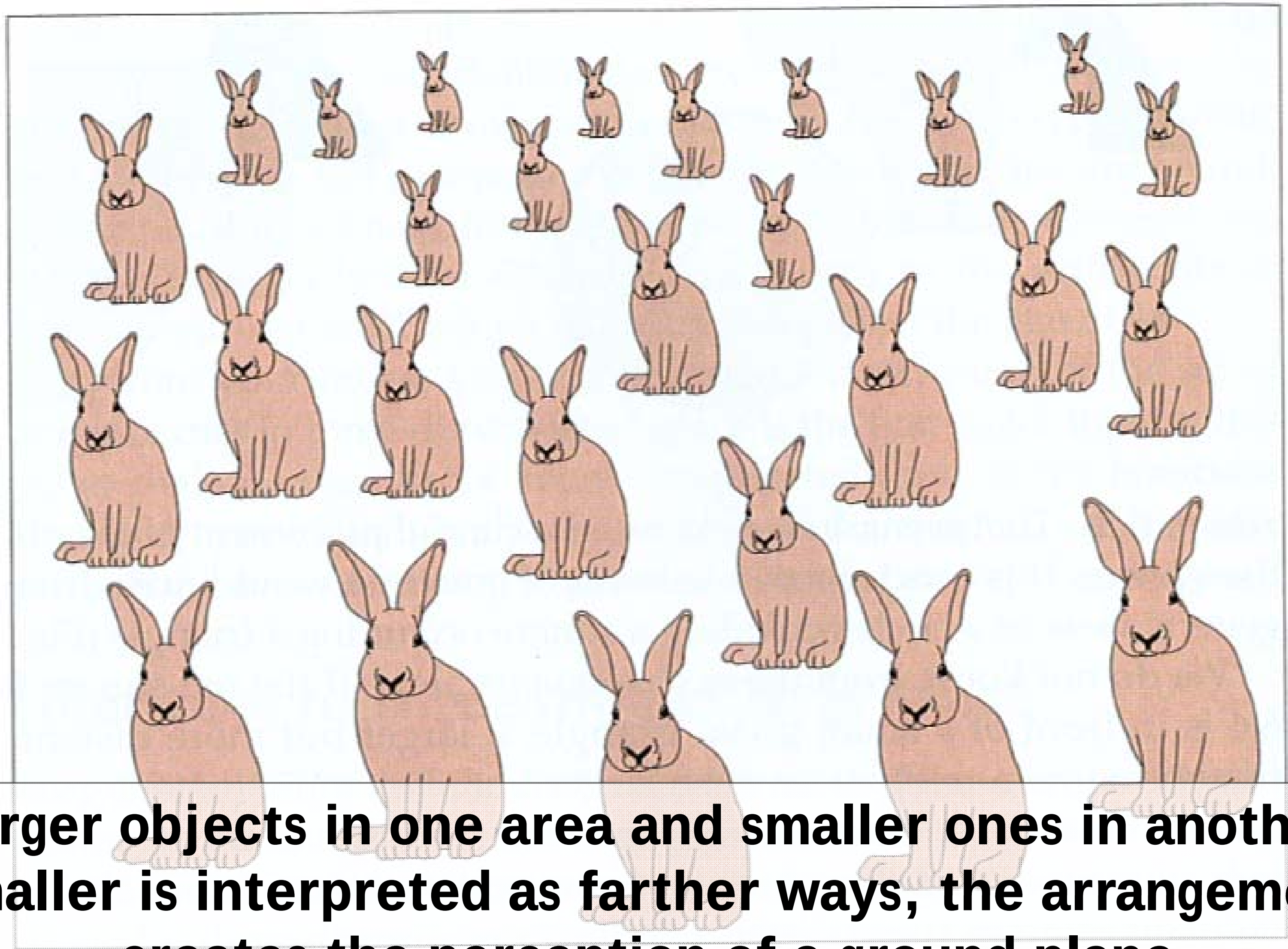


Size and position cues

- We have projective geometry embedded. We know that, all else being equal, smaller things are farther away.

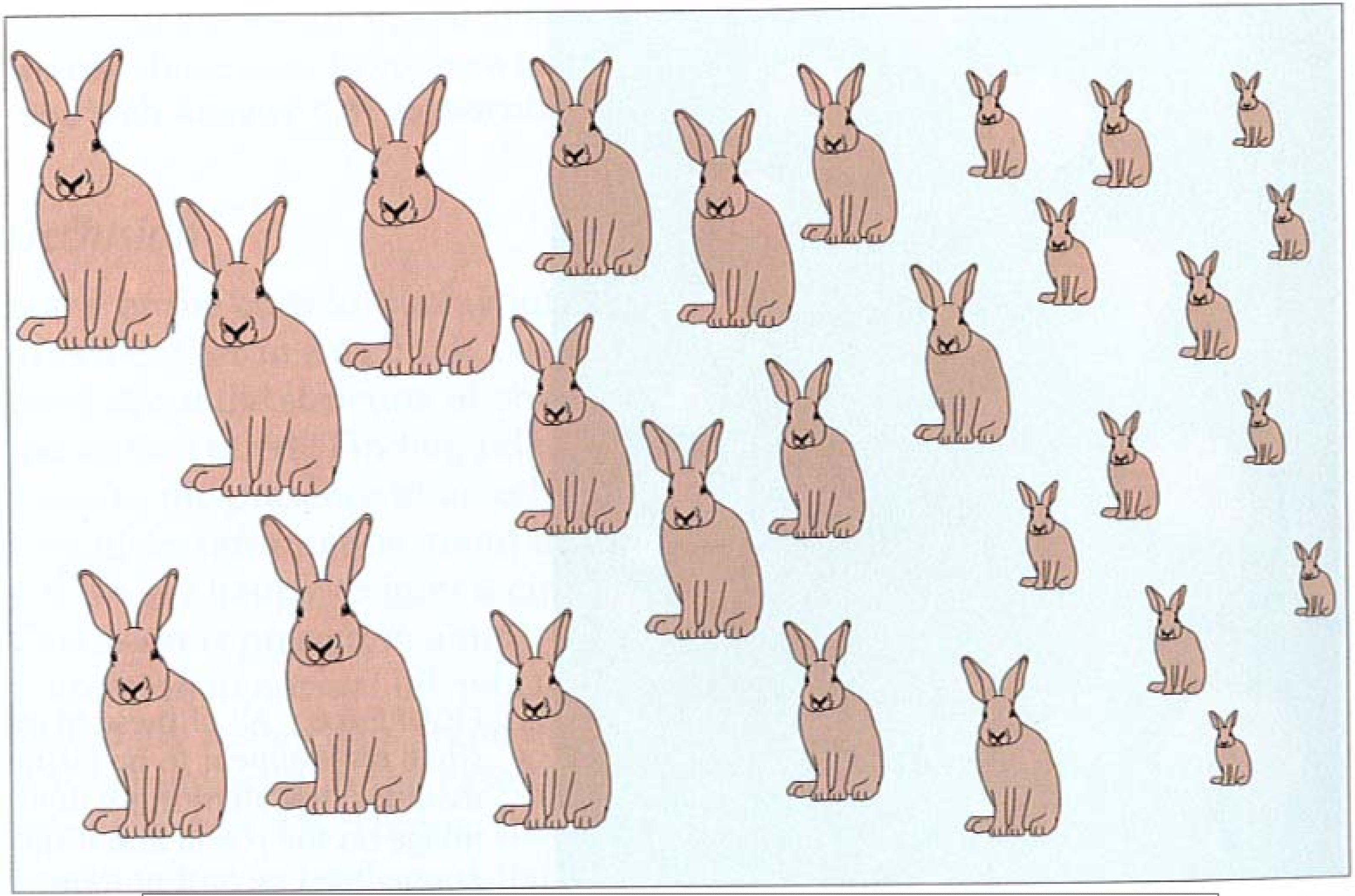


Texture gradient



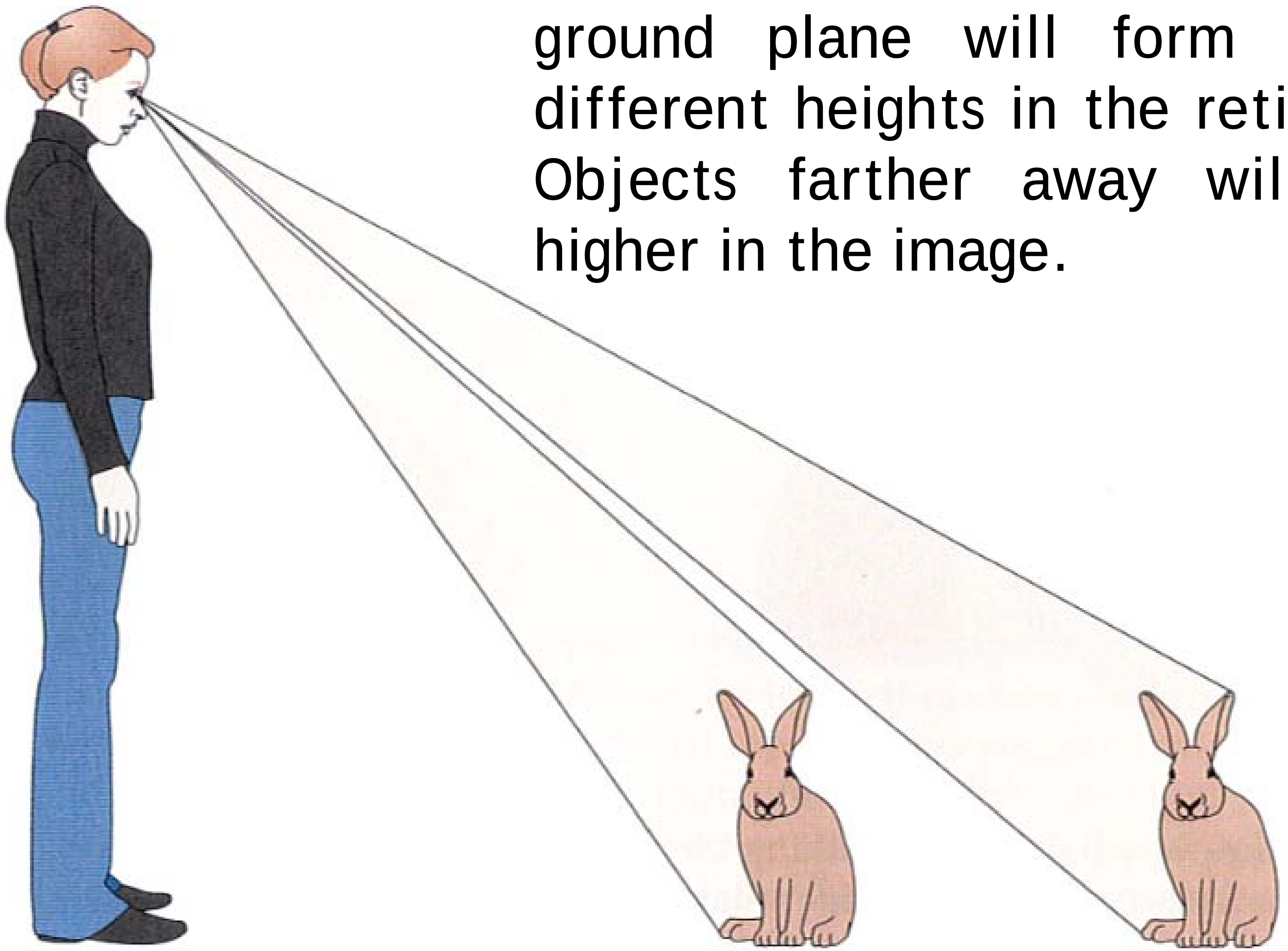
Larger objects in one area and smaller ones in another. Smaller is interpreted as farther ways, the arrangement creates the perception of a ground plane.

Texture gradient



Why do we get less of a sense of depth?

Relative height

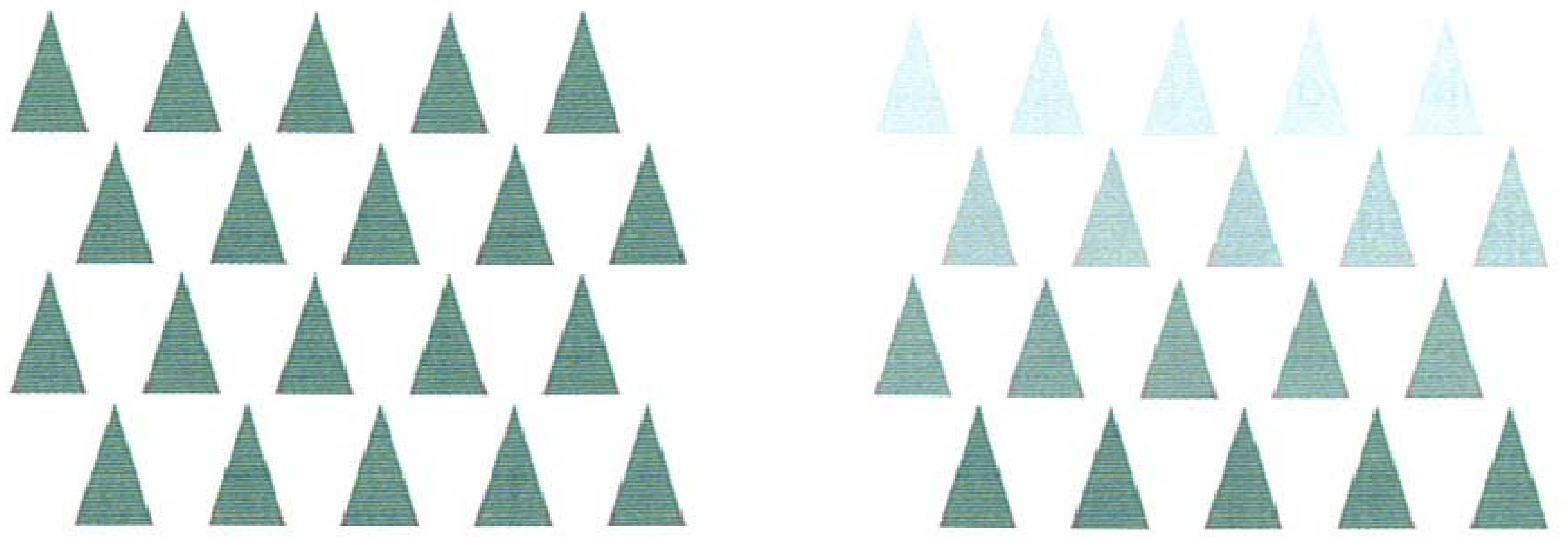


Objects at different distances on the ground plane will form images at different heights in the retinal image. Objects farther away will seen as higher in the image.

Familiar size

Familiar size: a depth cue based on knowledge of the typical size of objects.

Aerial perspective

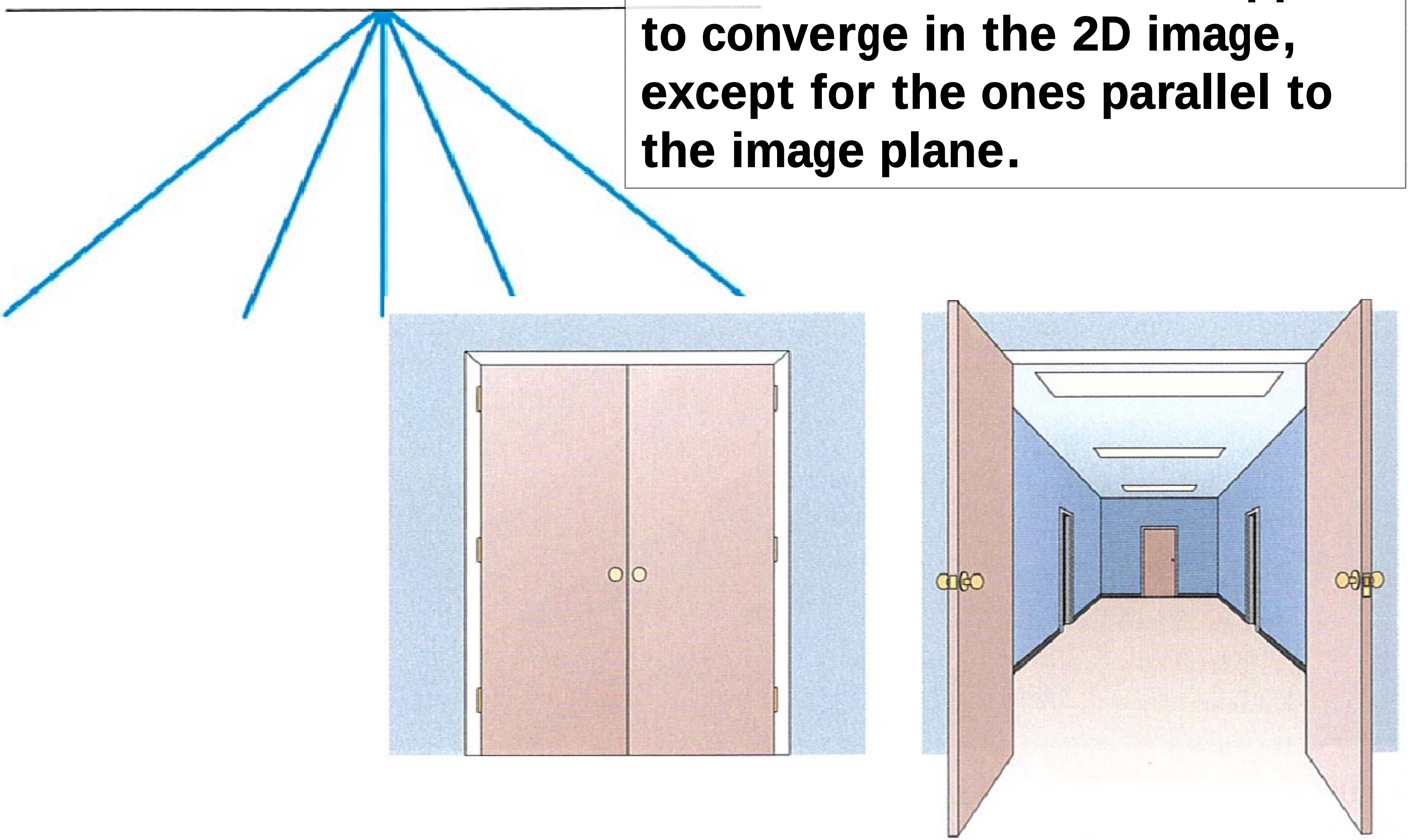


Aerial (haze) perspective: light is scattered by the Atmosphere, and more light is scattered when we Look through more atmosphere.

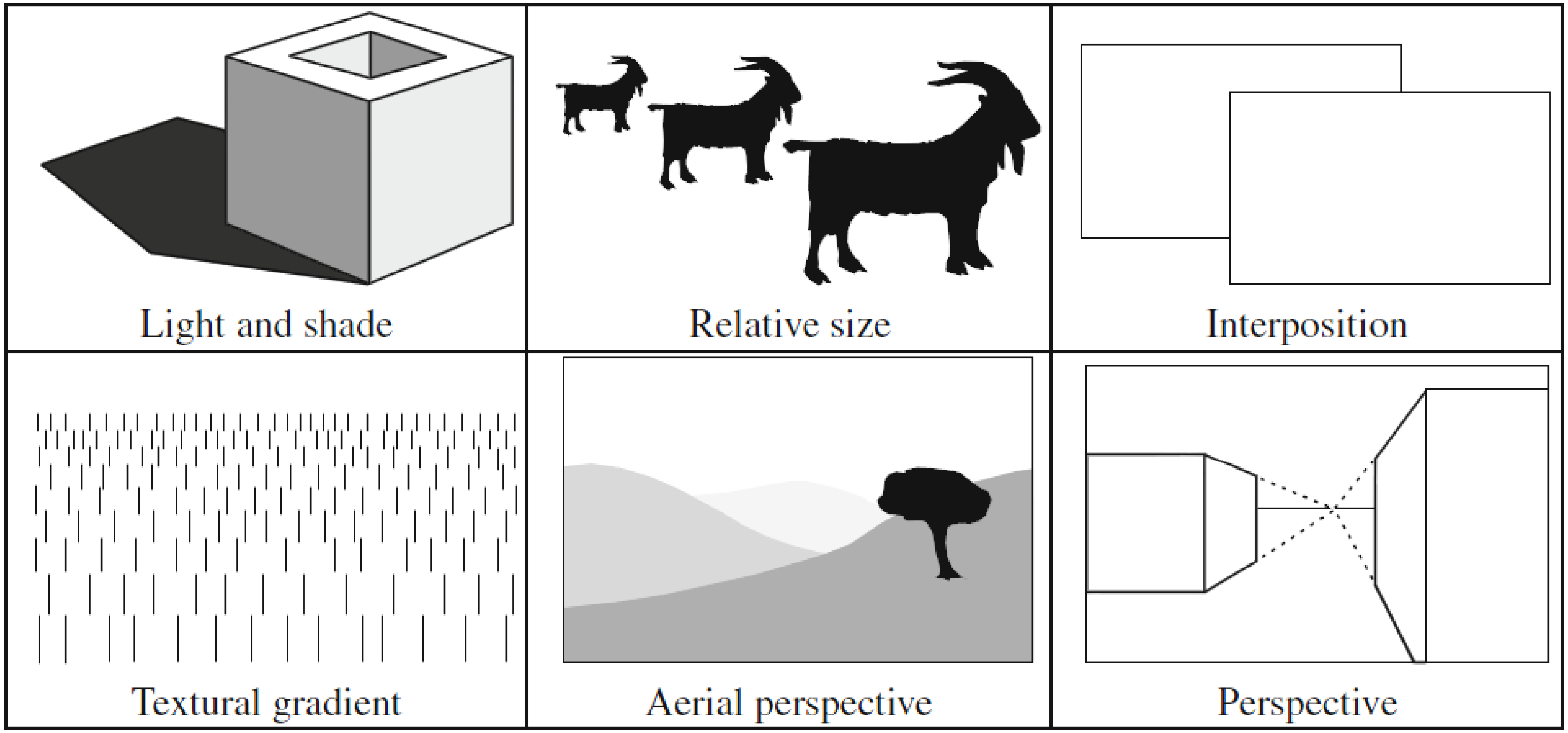
Aerial perspective

Linear perspective

Parallel lines in 3D world appear to converge in the 2D image, except for the ones parallel to the image plane.



Monocular cues

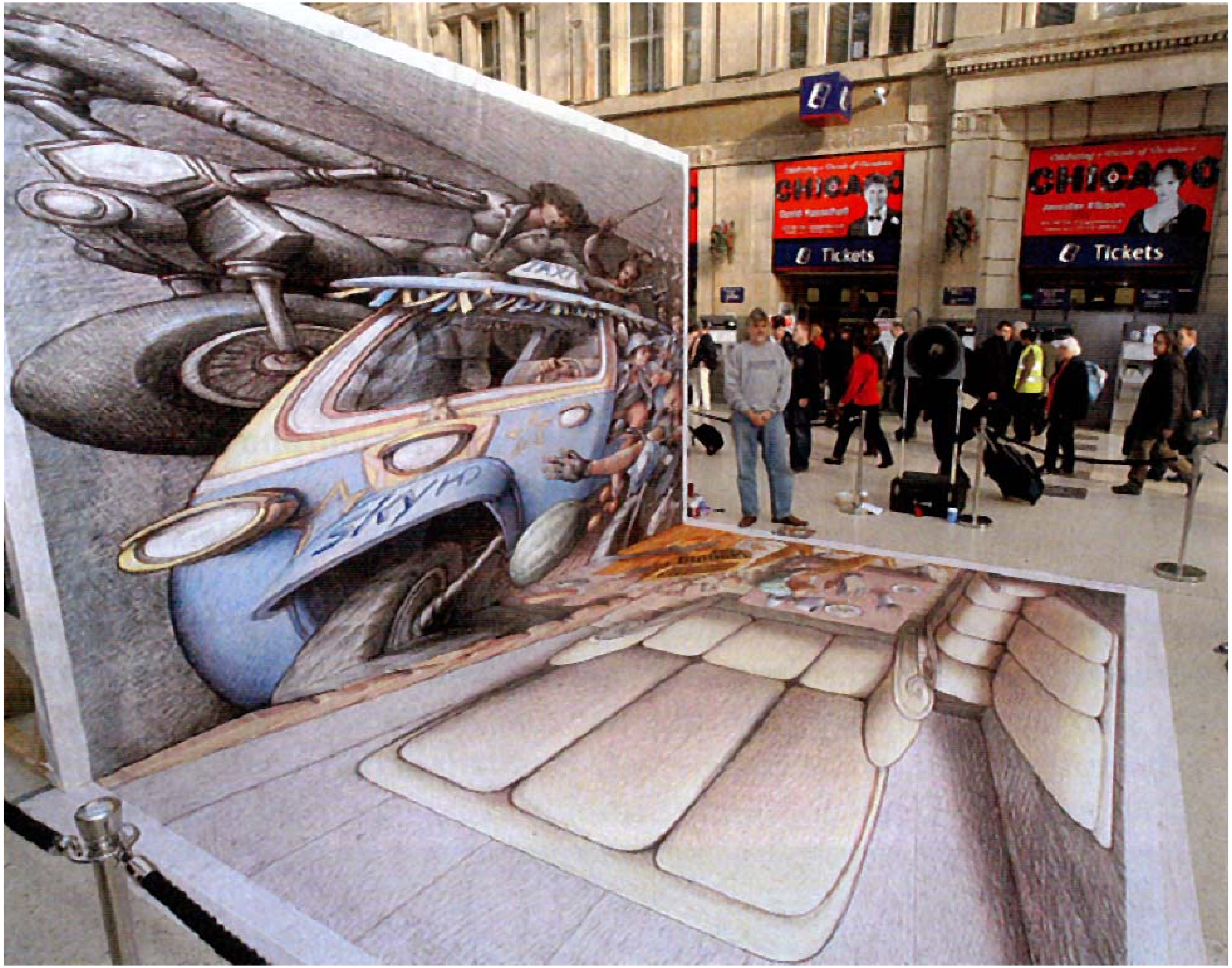


Pictorial depth cues

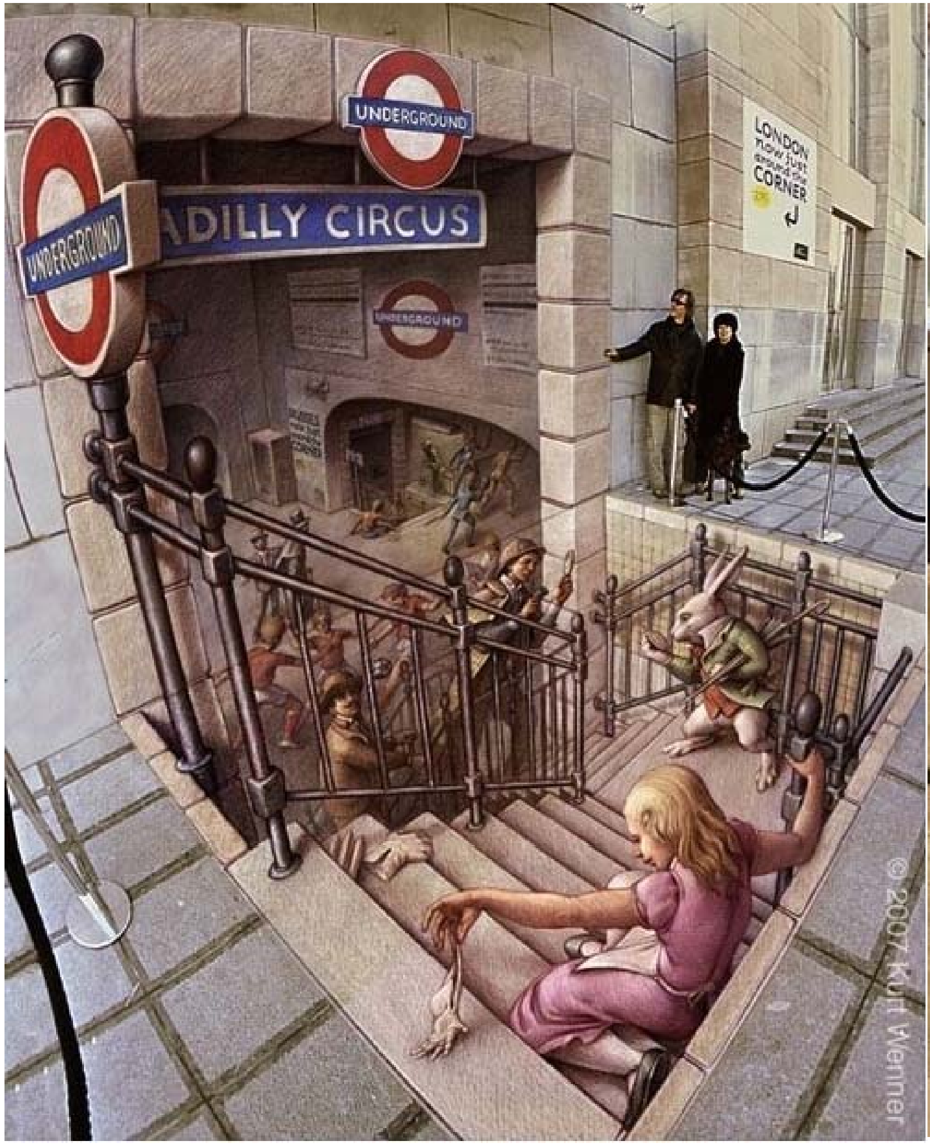
- All these monocular cues are pictorial depth cues produced by the projection of the 3D world onto the 2D surface of the retina.
- Combined with proper shading, these cues could be effective in illustrating 3D.

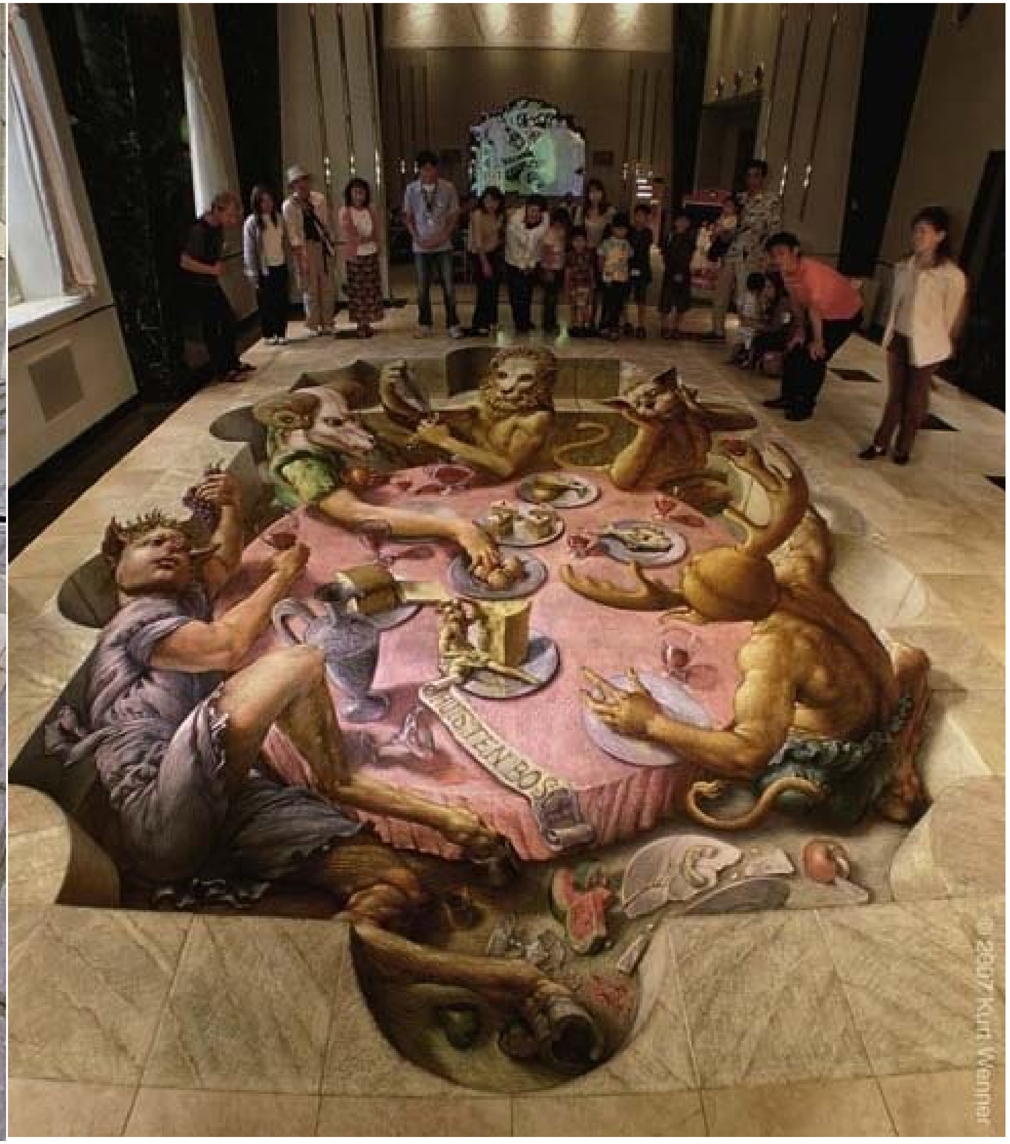
Pictorial depth cues

Pictorial depth cues



Pictorial depth cues



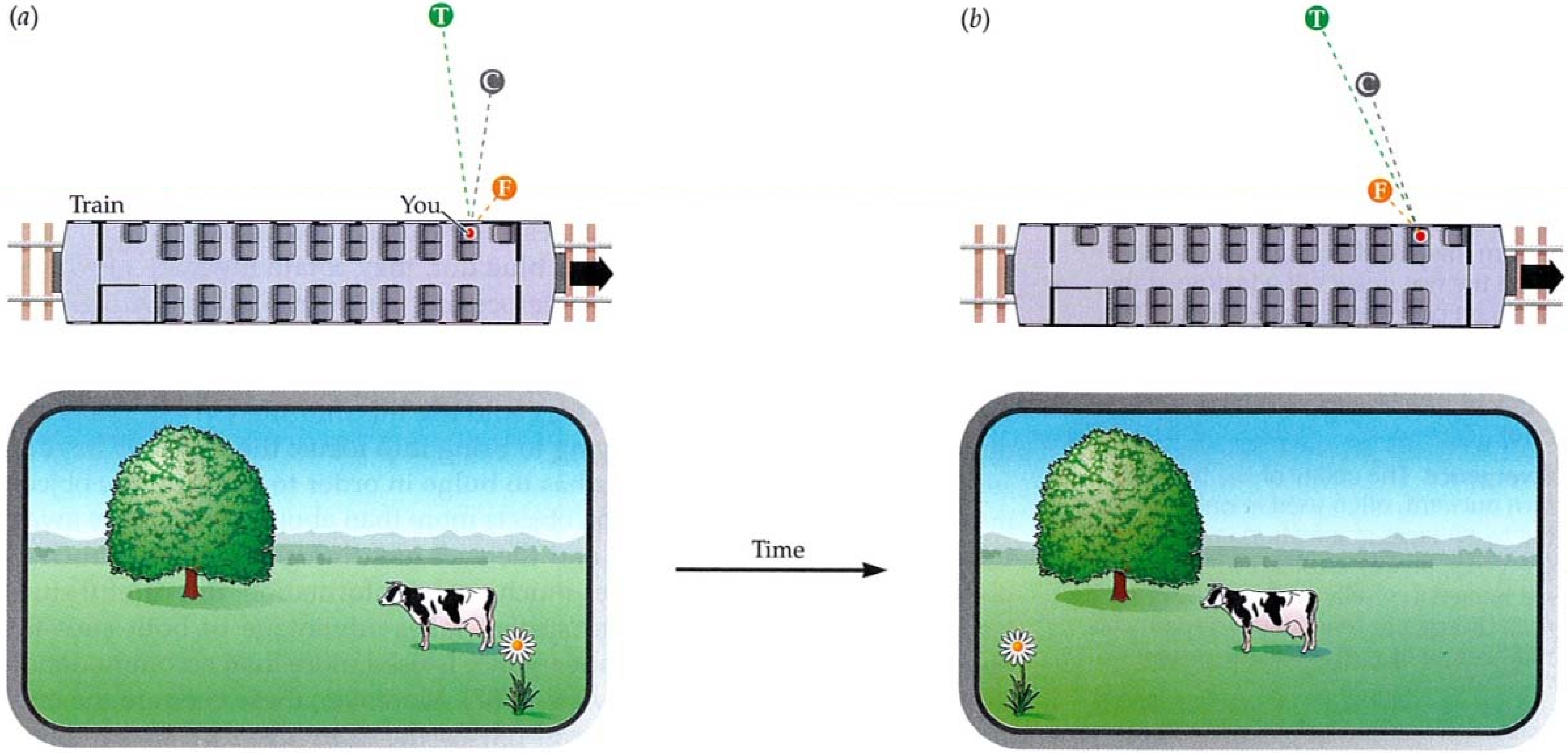


Monocular cues

- Because there are lots of monocular cues and they are not less important than binocular ones, some images could look more stereoscopic than others. Example, 2D-to-3D conversion is easier for some images but more difficult for others.

Motion cues

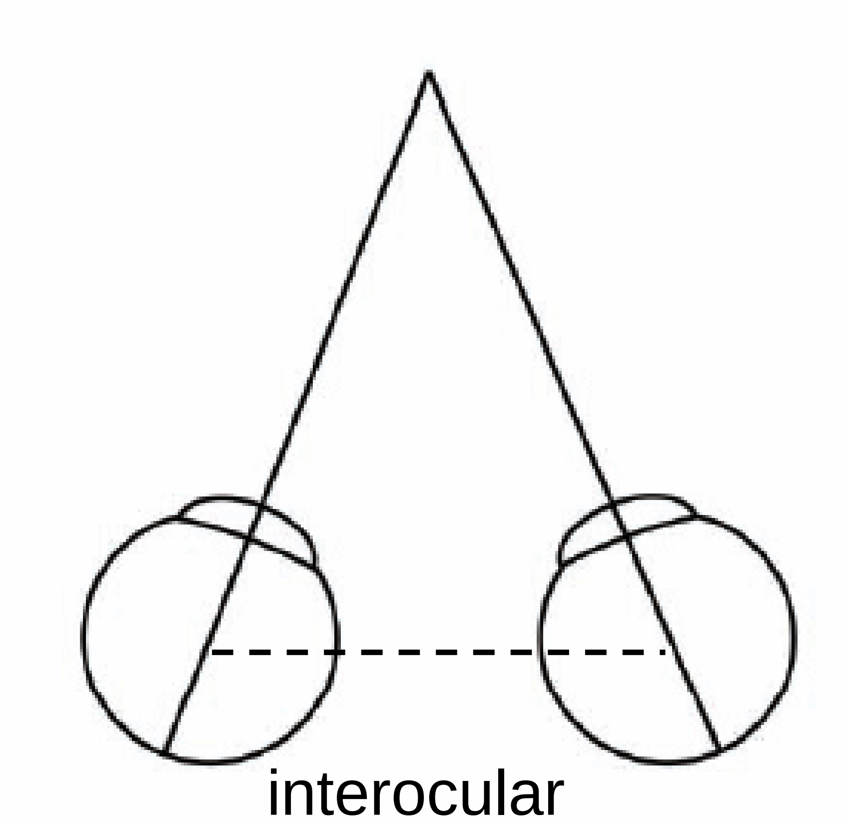
- **Motion parallax** is a non-pictorial depth cue. When your head moves, closer objects move faster than more distant ones.



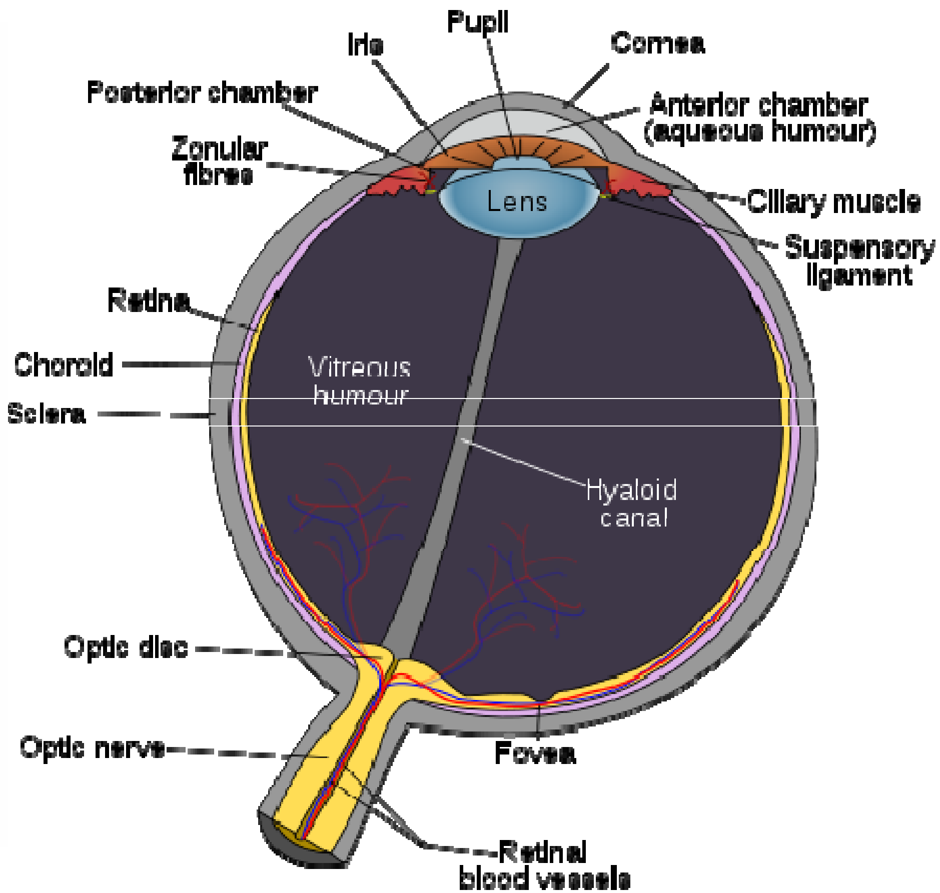
Motion cues

- A very effective depth cue but it relies on head movements.
- Some 3D games are designed this way.

Binocular vision

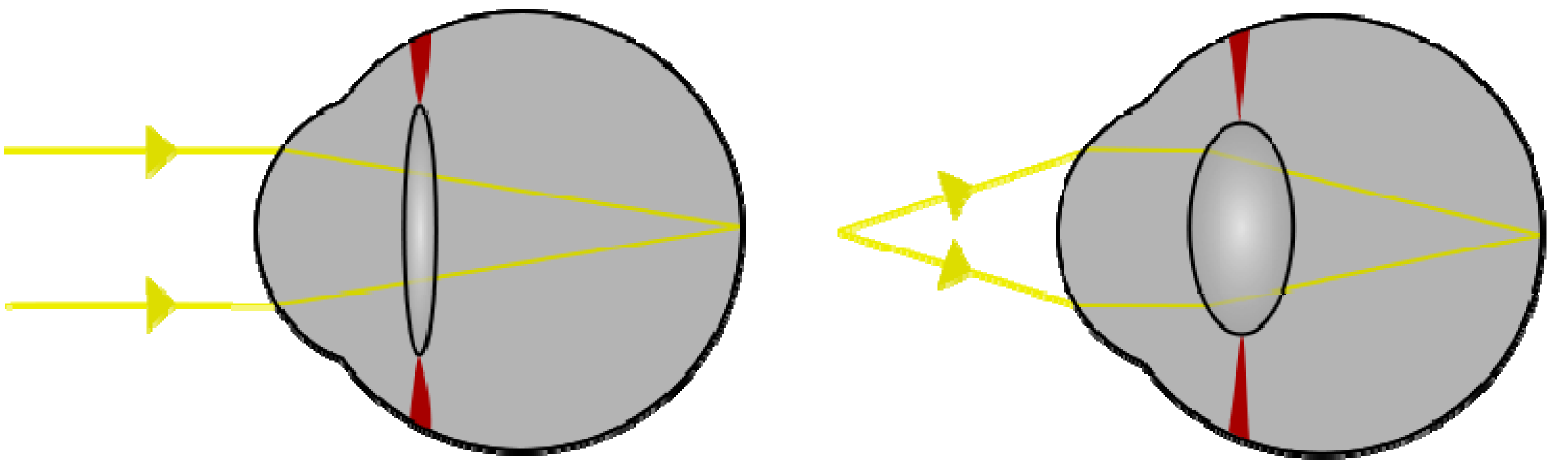


interocular distance ~6.5cm

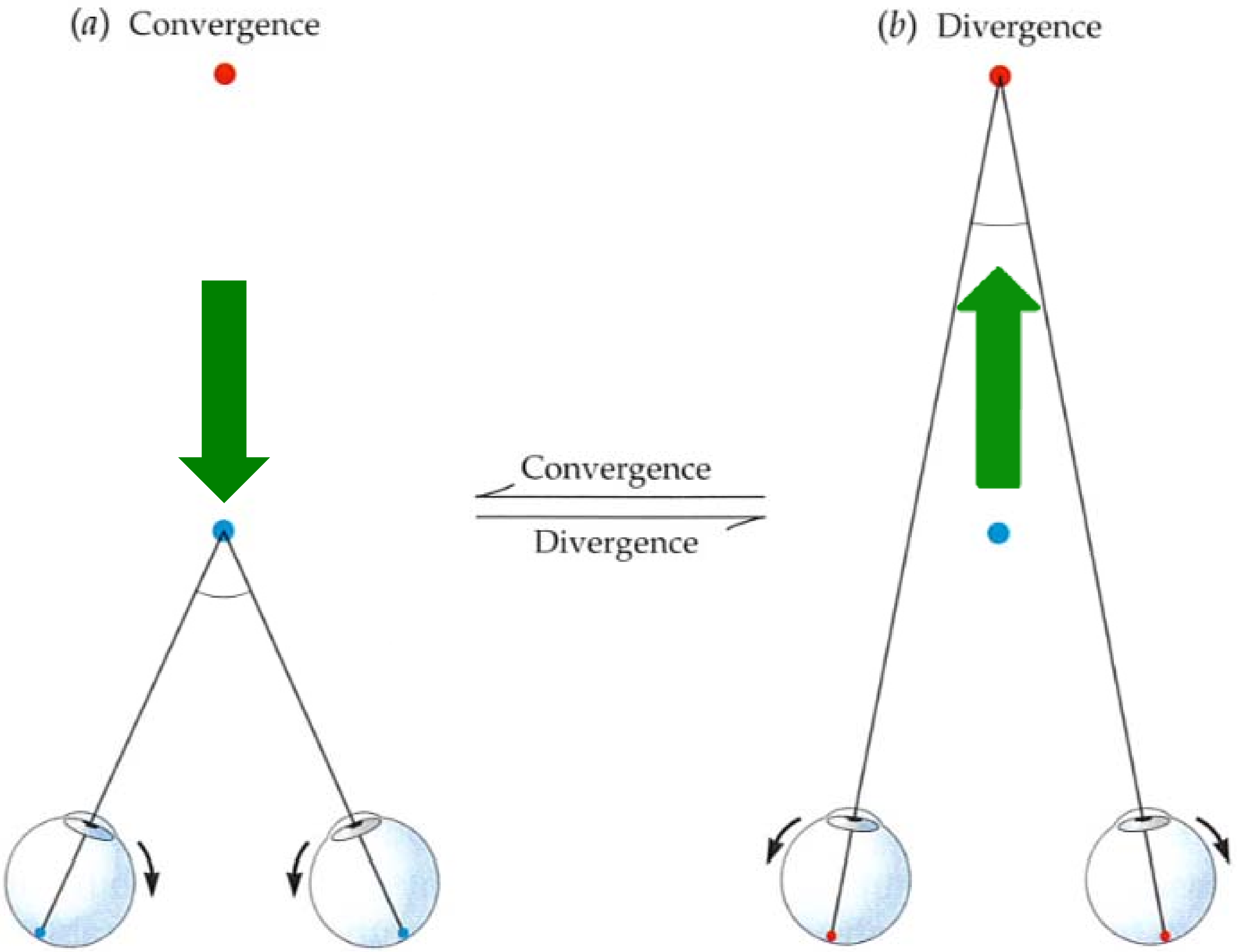


Accommodation and convergence

- Eyes need to be focused to see objects at different distances clearly.
- Human eye focuses via a process called accommodation, in which lens gets fatter as we direct our gaze toward nearer objects.



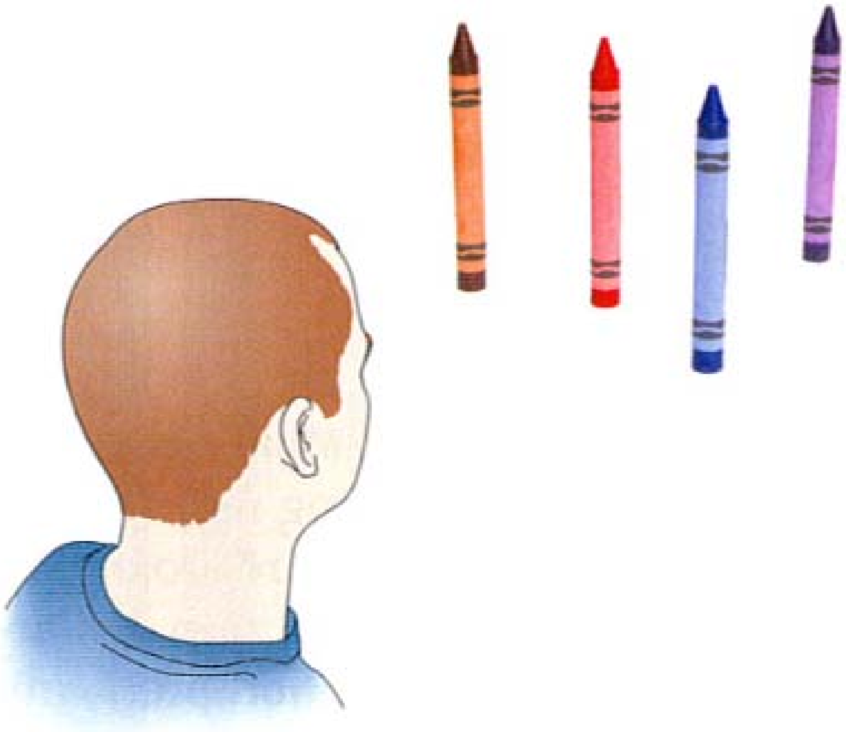
Accommodation and convergence

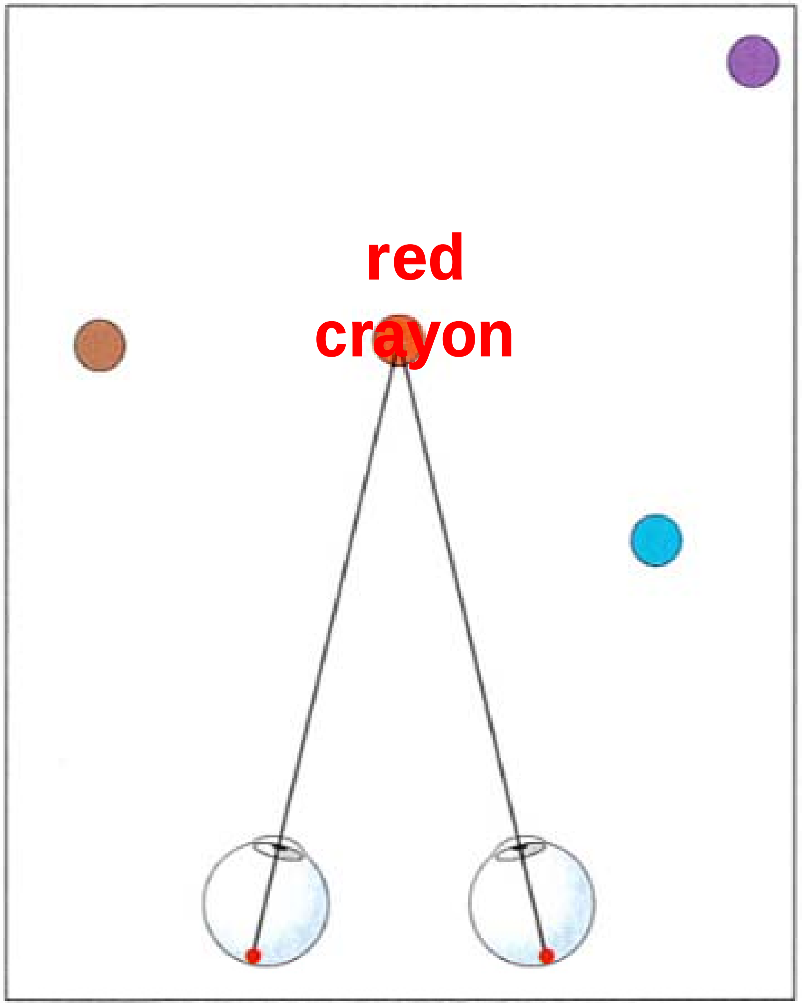


Accommodation and convergence

- Human can perceive depth by accommodation and convergence.

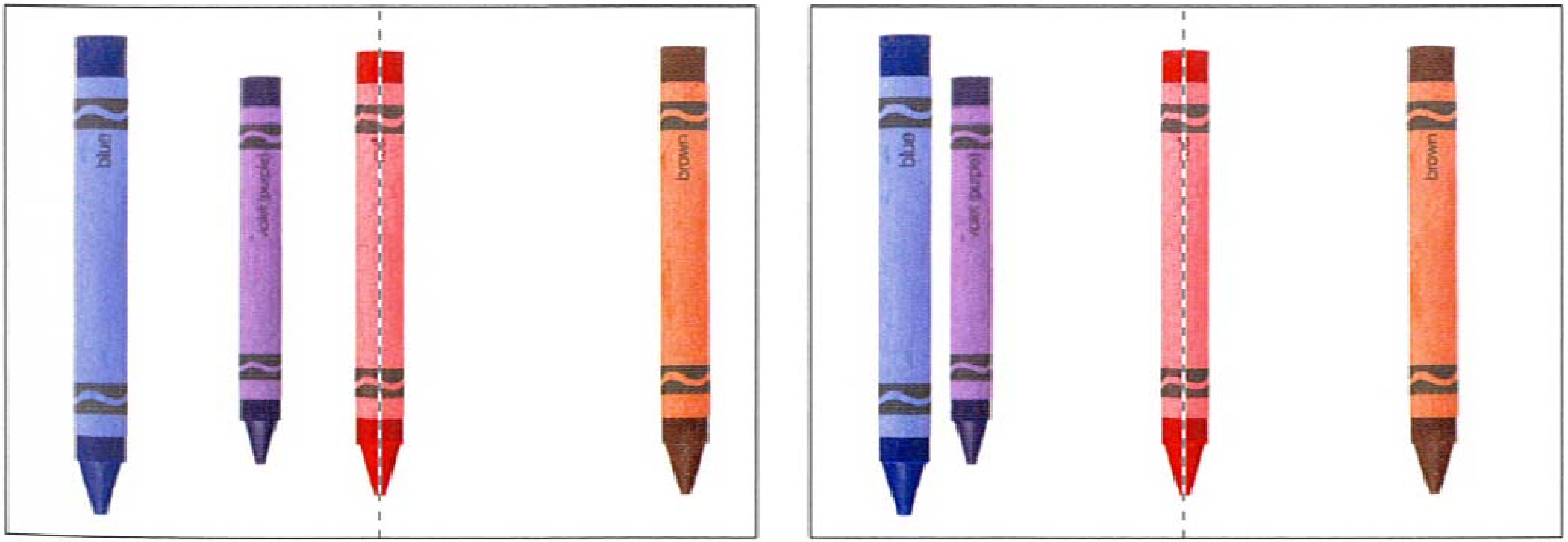
Binocular vision





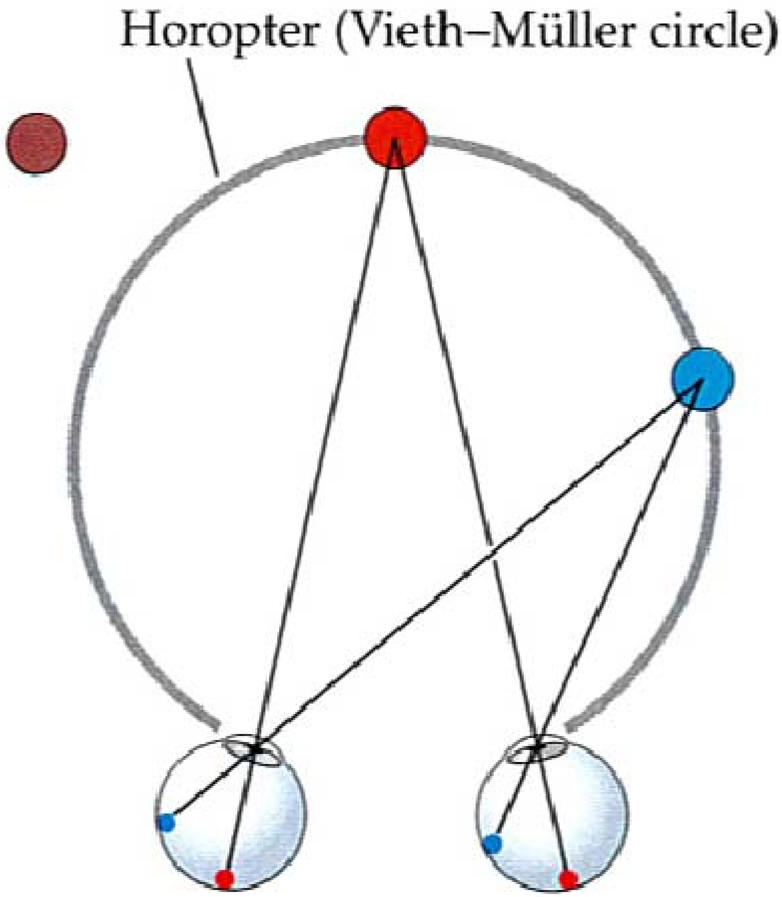
Binocular vision

- Note that the retinal images are inverted. The object of our gaze falls on the fovea, center of the retina.
- The blue one happens to fall on **corresponding retinal points**.



Left retinal image   Right retinal image

Binocular vision

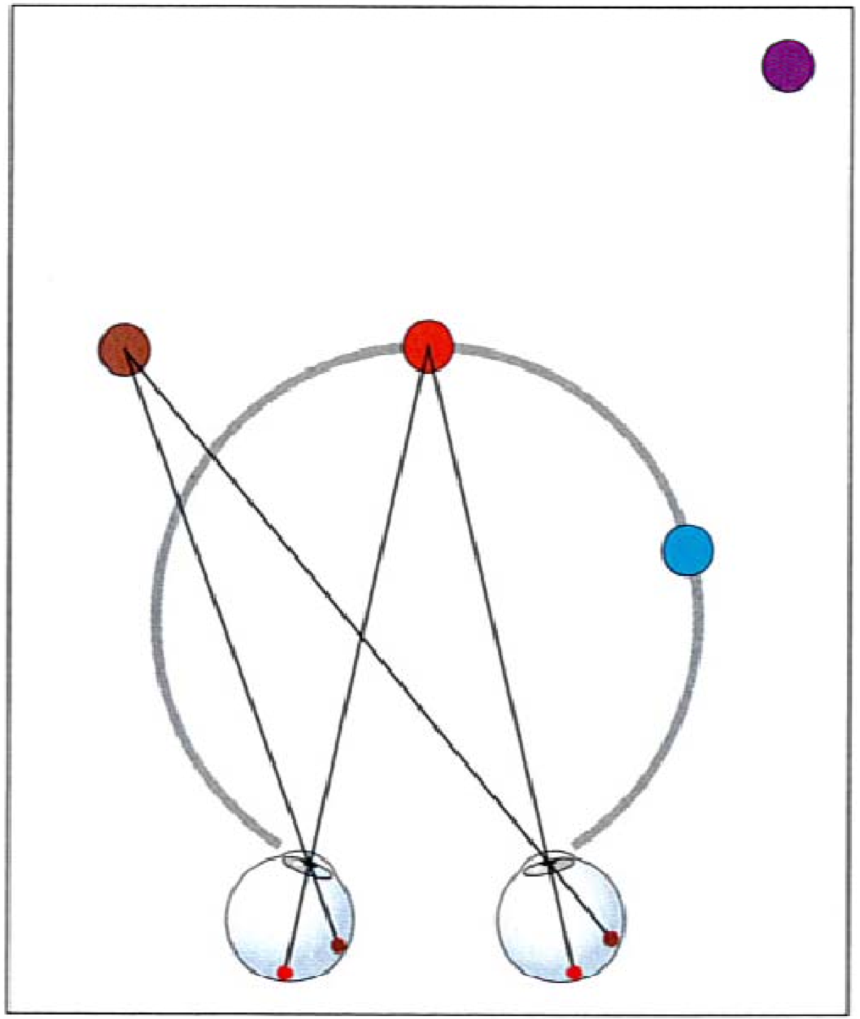


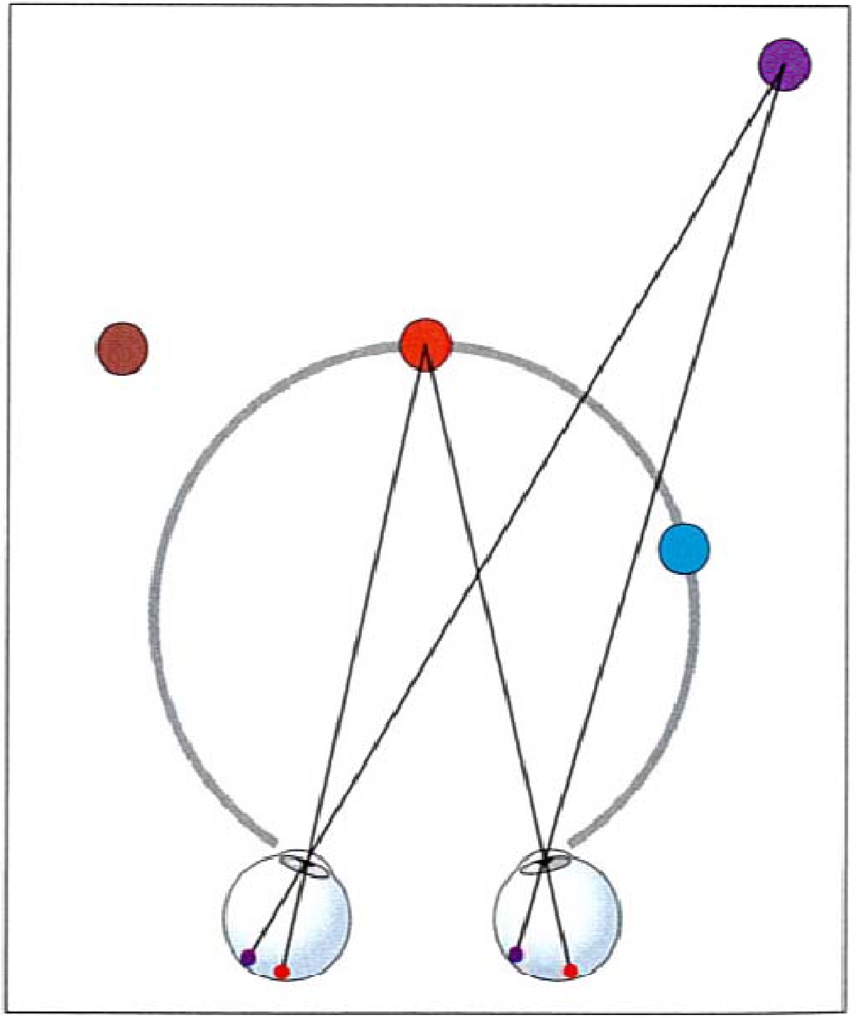
- **Horopter**: the surface with zero disparity.

Panum's fusional area: the region of space, in front of and behind the horopter, within which binocular vision is possible.

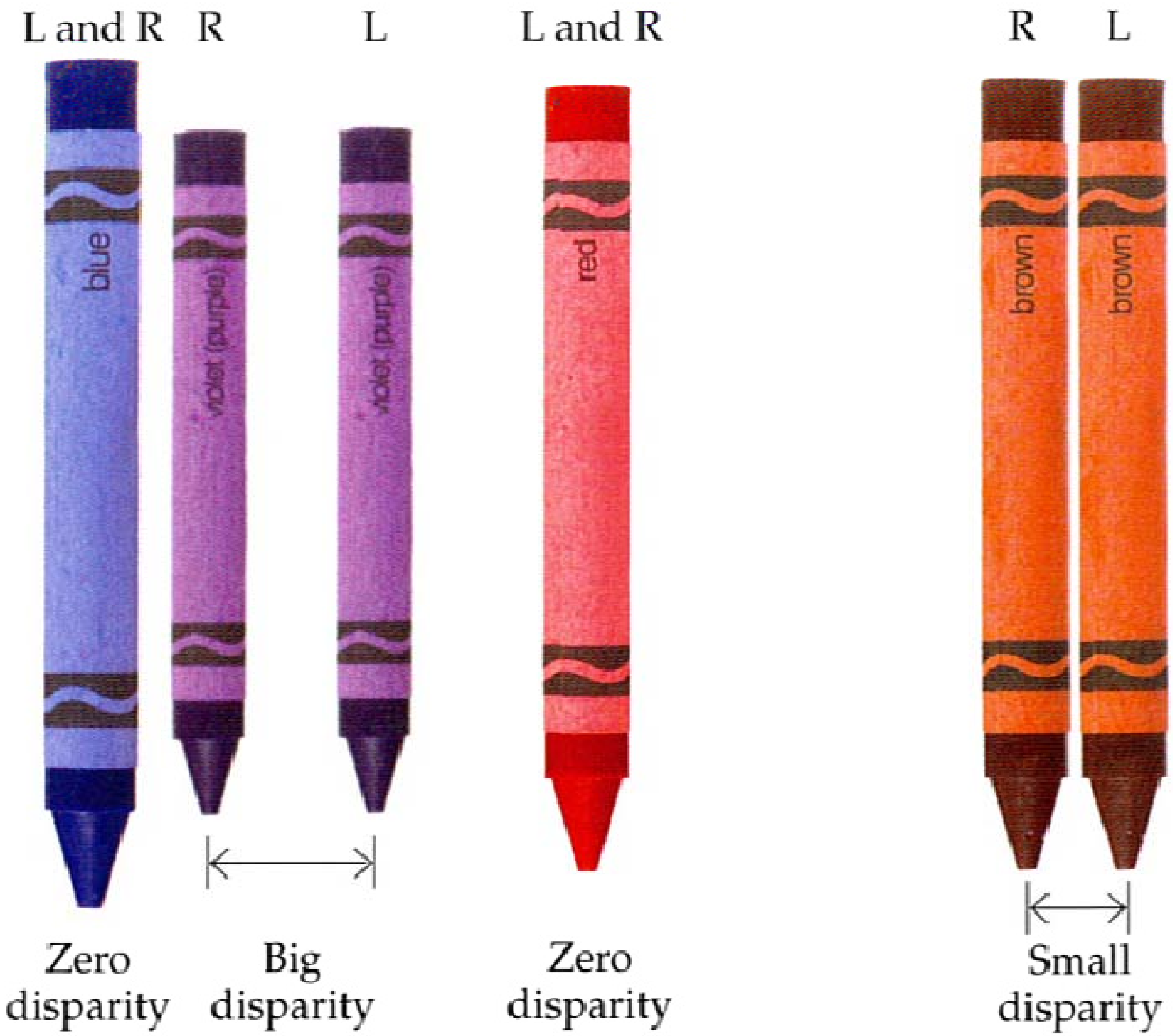
Diplopia: double vision

Binocular vision





Binocular vision



Binocular vision

Binocular vision

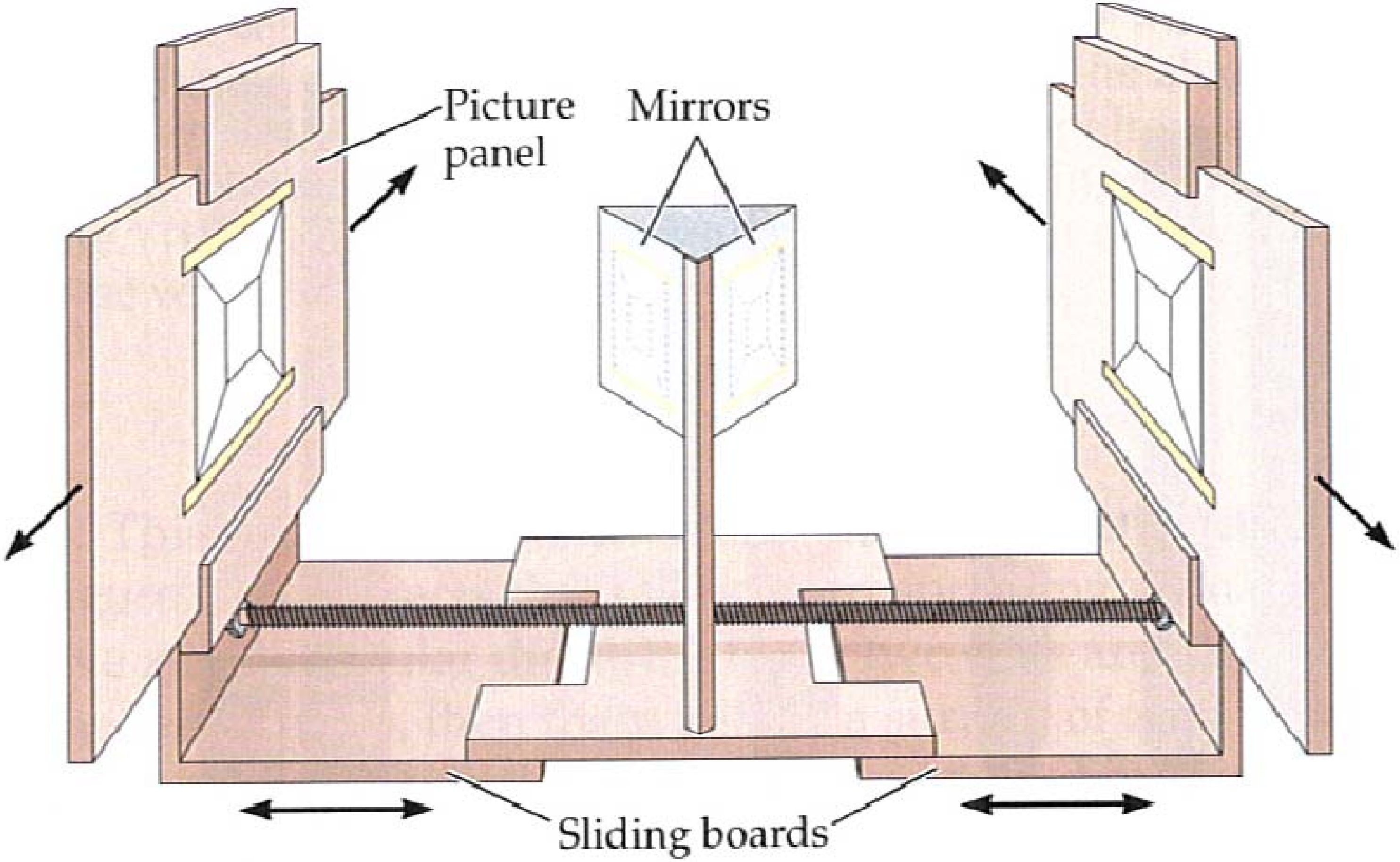
Binocular vision

Binocular vision

- Our nervous system cannot measure the angle very accurately. Thus, we can only perceive relative depth.
- The role of eye movement is to bring the images within Panum's fusional area.

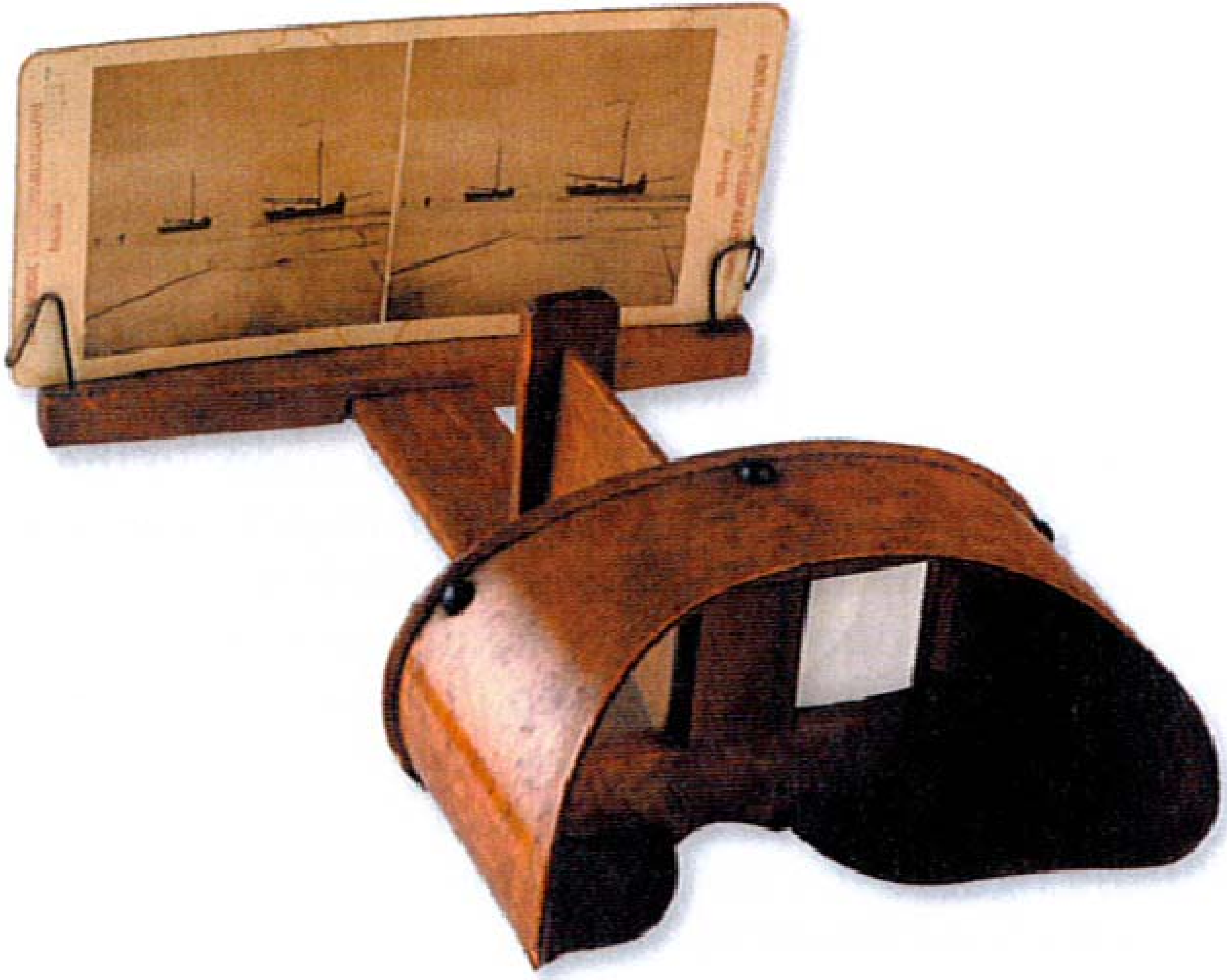
Stereoscope

- Invented by Sir Charles Wheatstone in 1830s. Our visual system treats binocular disparity as a depth cue, no matter it is produced by actual or simulated images.

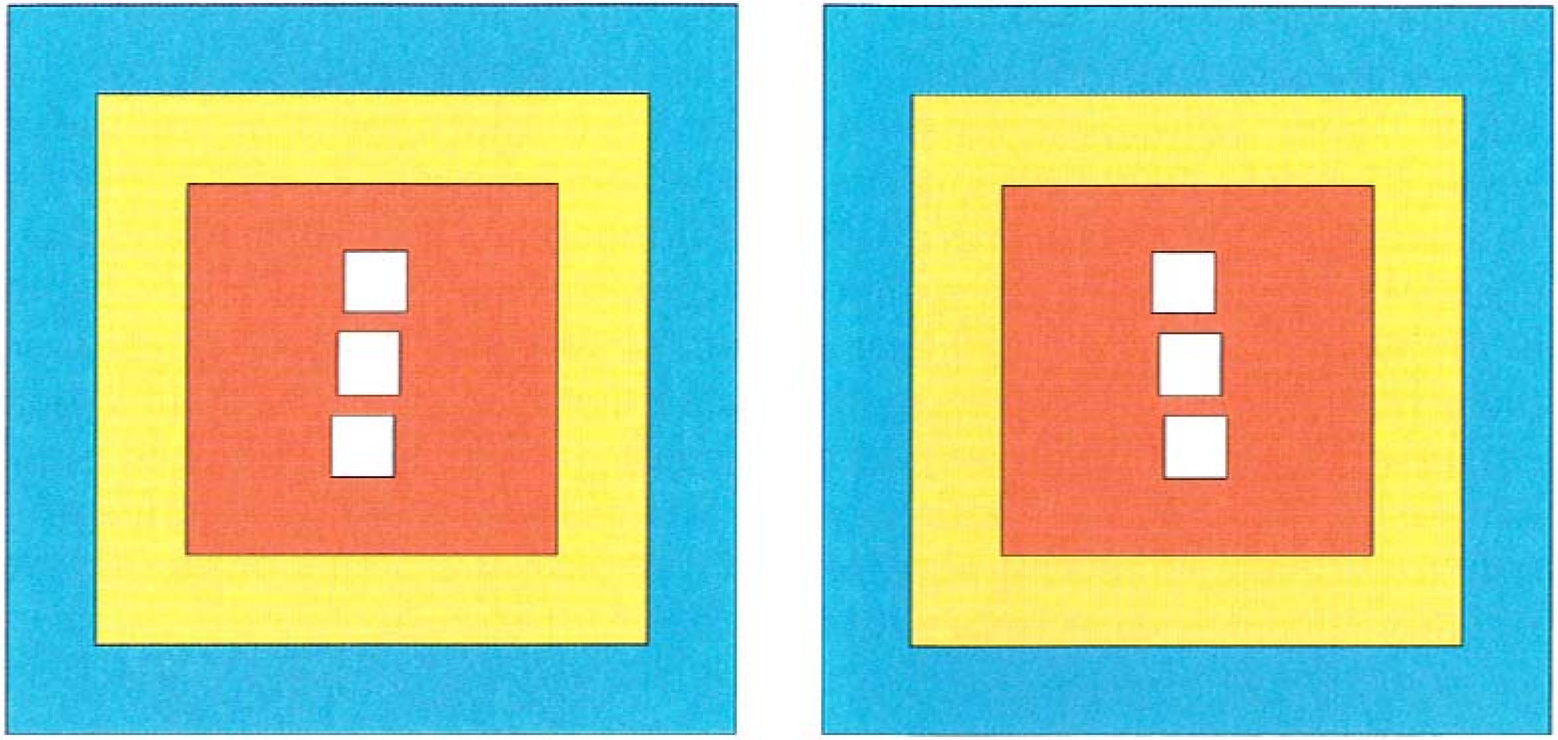


Stereoscope

- Invented in 1850s, it is stereopsis for the masses.



Free vision

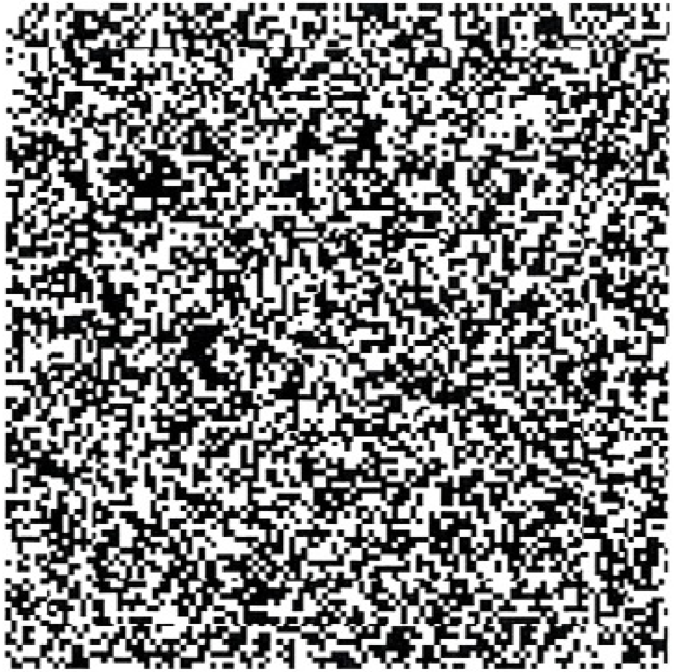


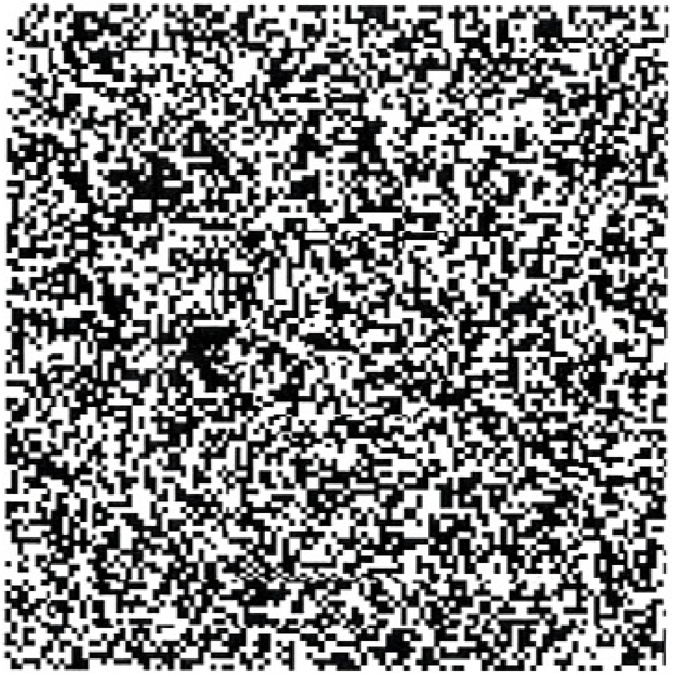
Random dot stereograms

- For 100 years after the invention of stereoscope, it is supposed that stereopsis occurred relatively late in the processing of visual stimuli; i.e. we recognize facial features and then use them to find depth.

Random dot stereograms

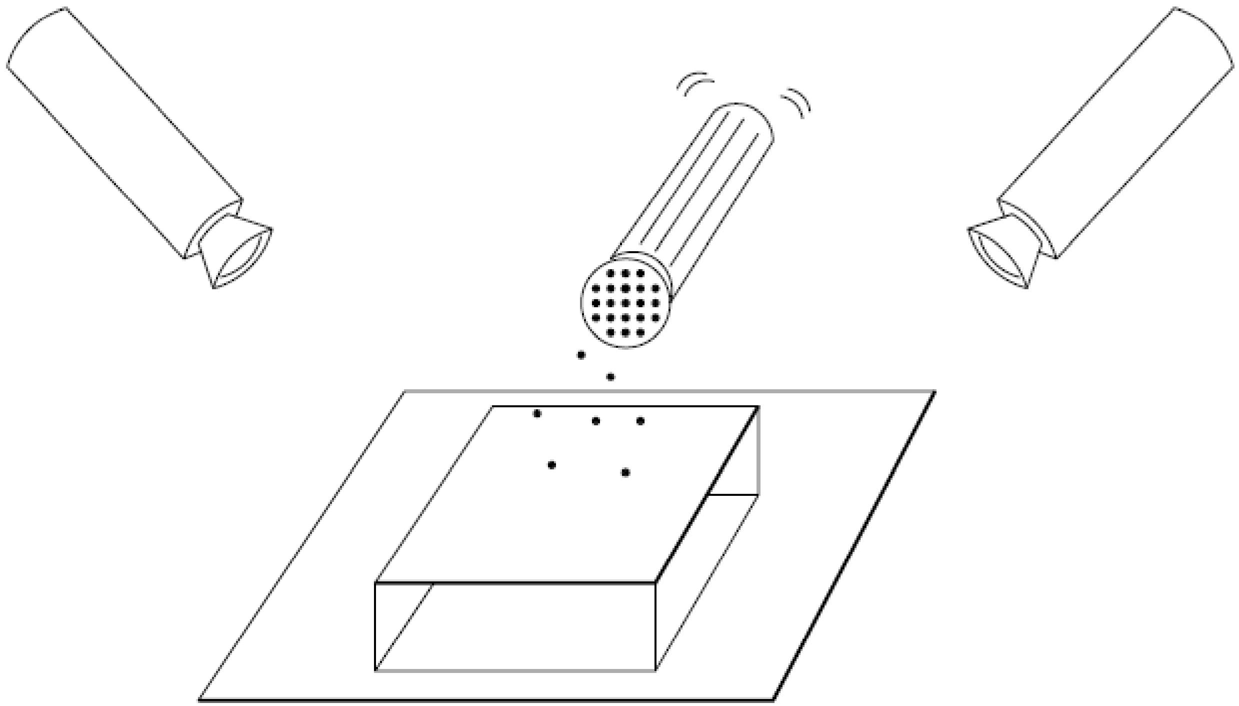
- Julesz thought that stereopsis might help reveal camouflaged objects (the example of cats and mice) and invented random dot stereograms.





Random dot stereograms

- Paint the scene in white and spray it with pepper.



Stereoblindness

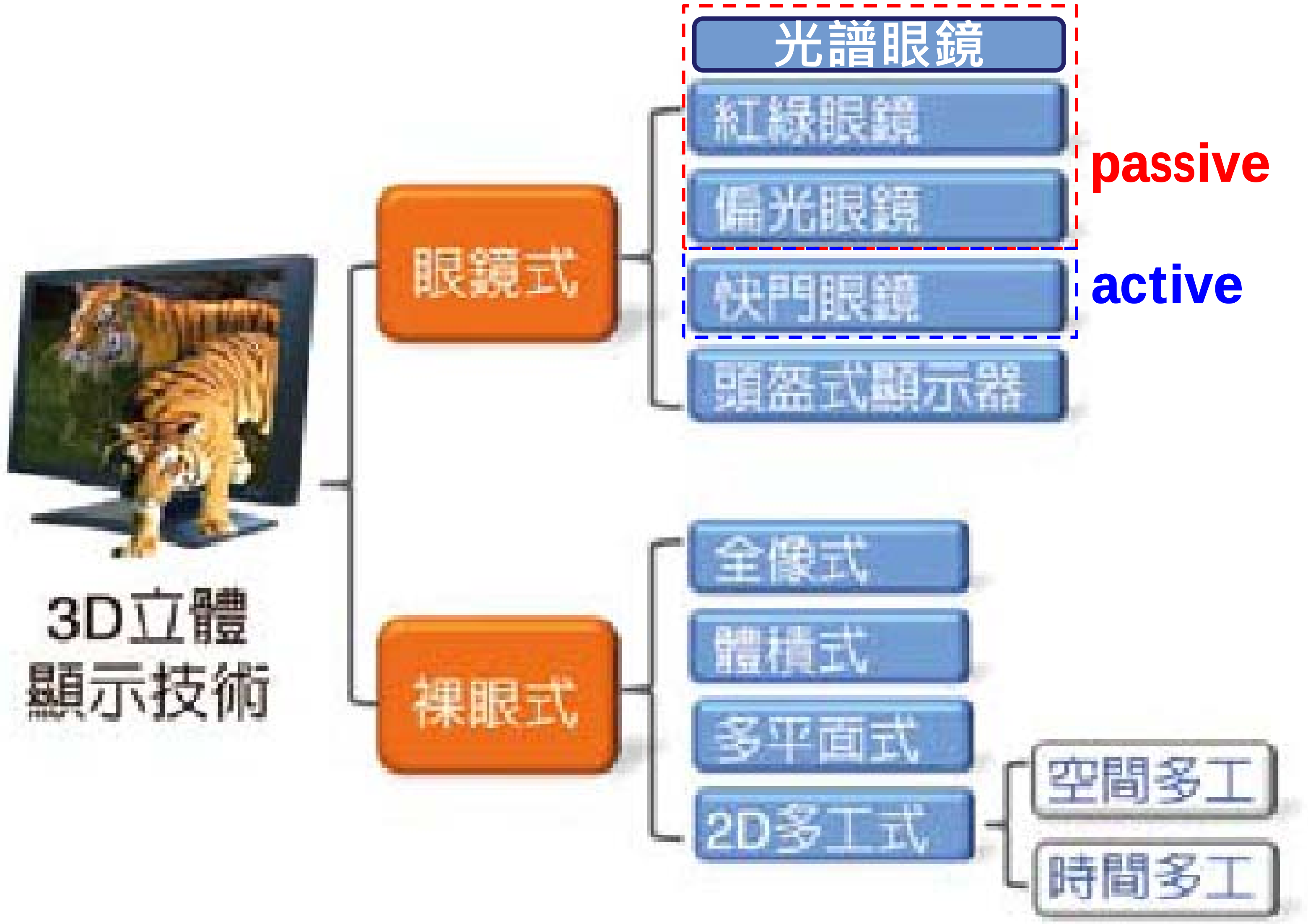
- An inability to make use of binocular disparity as a depth cue.
- Approximately 3% to 5% of the population lacks stereoscopic depth perception.

Summary

- Monocular cues: occlusion, size and position cues, aerial perspective, linear perspective.
- Motion cues
- Accommodation and convergence cues
- Binocular cues: resolve stereo correspondence problem, Panum's area.

3D displays

3D displays



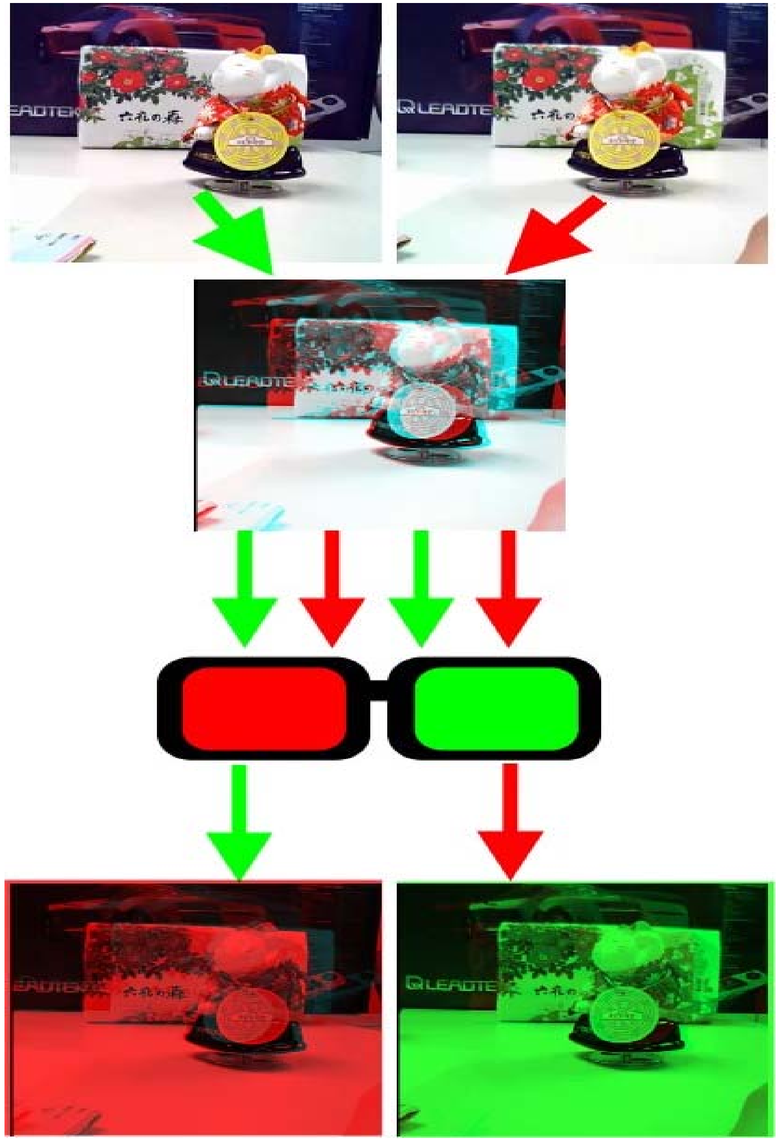
3D立體顯示技術的分類

3D displays

- Note that monocular cues can be produced by rendering/capturing the contents correctly.
- Most 3D displays enrich space perception by exploiting binocular vision. Thus, they have to present different contents to each of both eyes.

With glasses

Anaglyph glasses

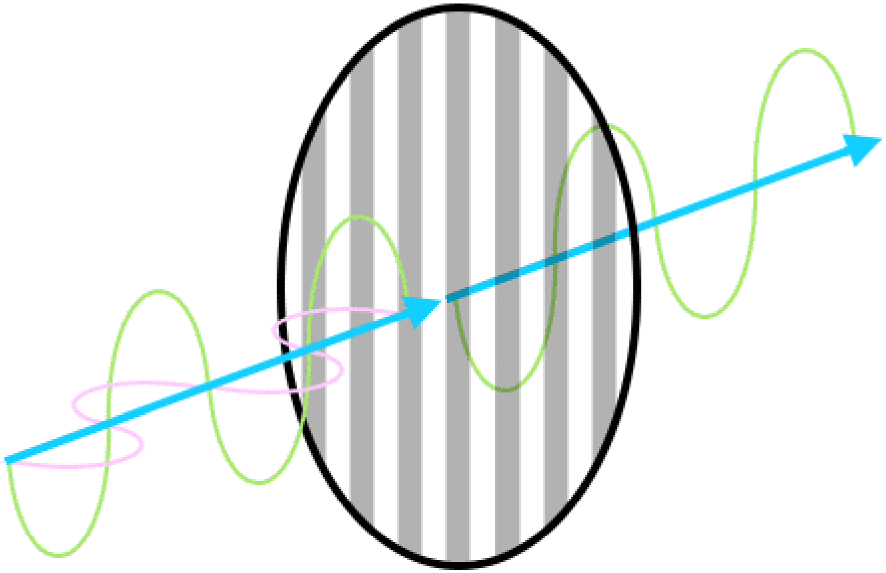


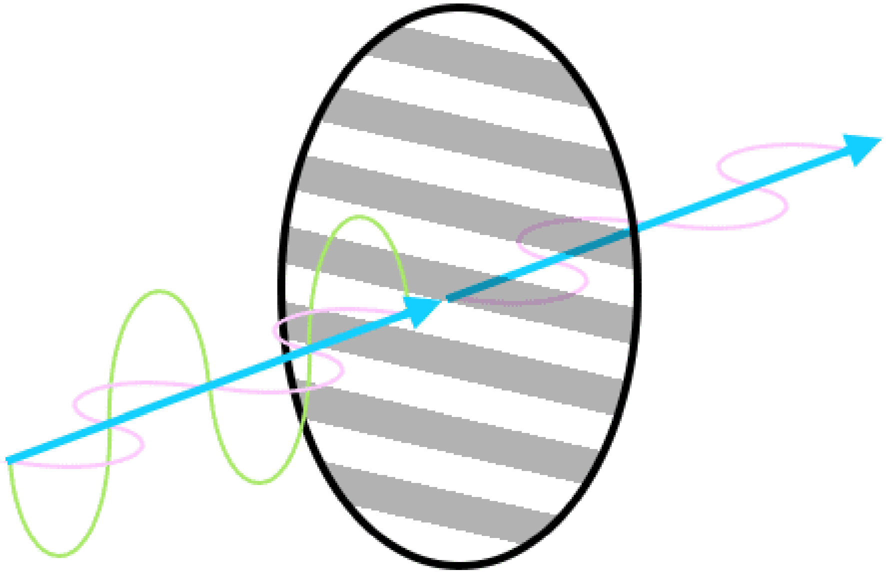
Many color formats
Supported by YouTube and
Google StreetView

Anaglyph glasses

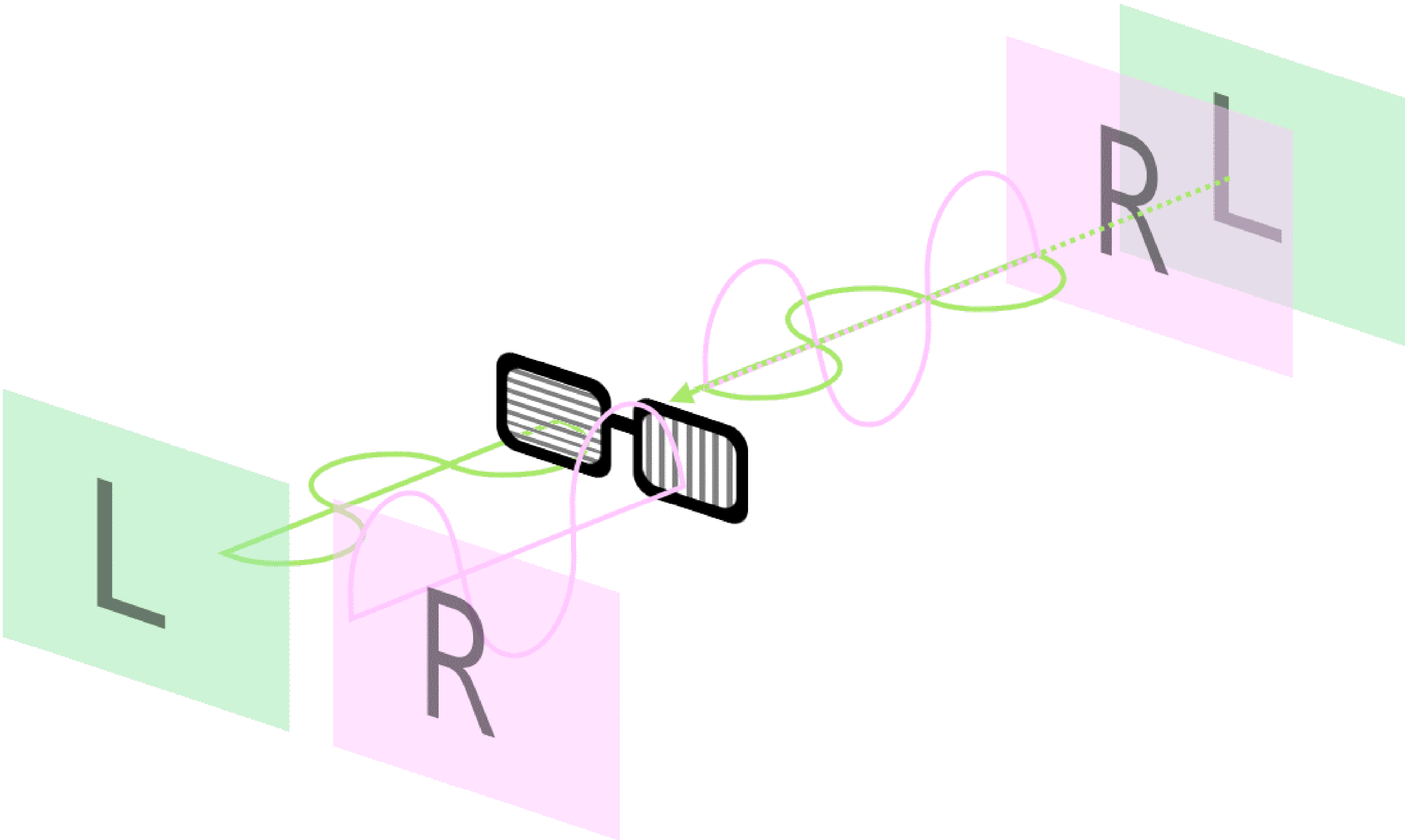
Pros: cheap (home-made)
Cons: without colors
bad 3D

Polarization glasses





Polarization glasses

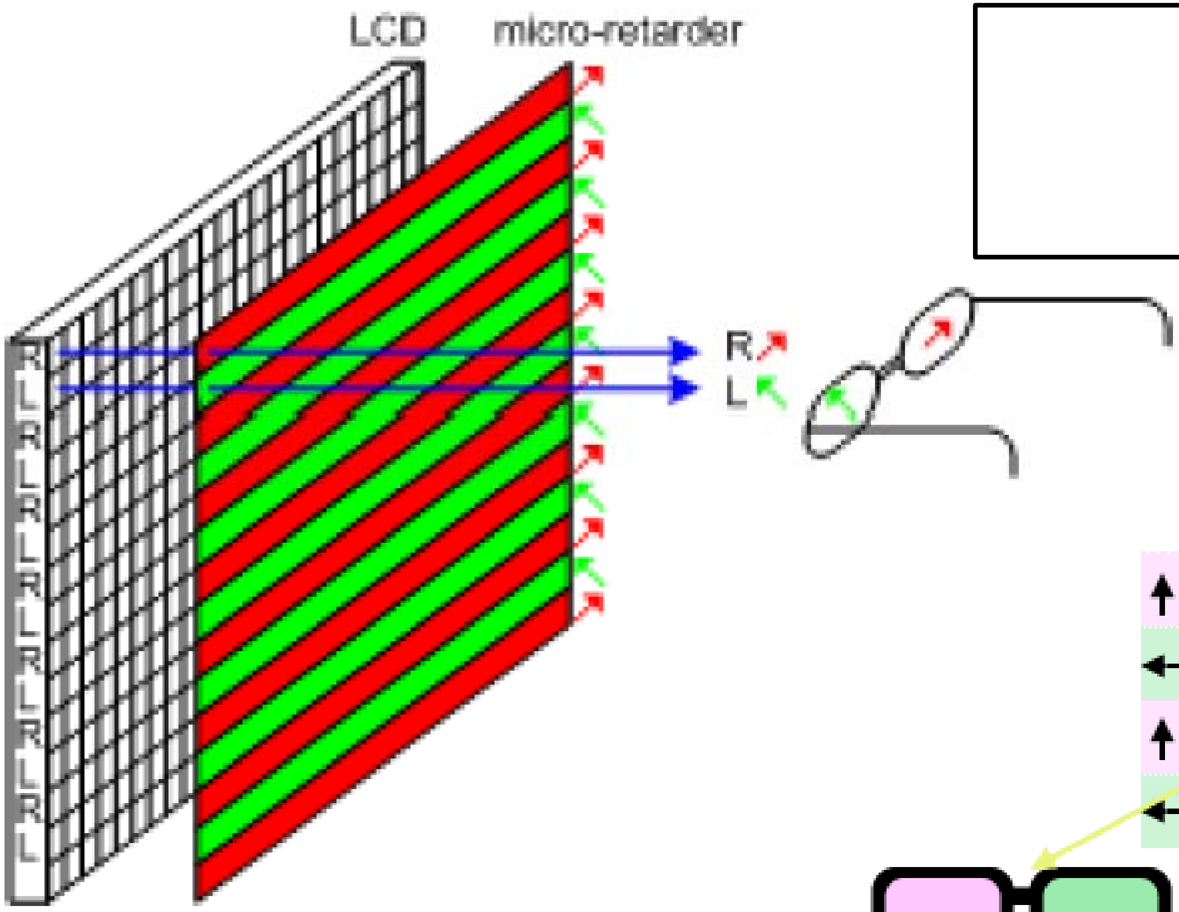


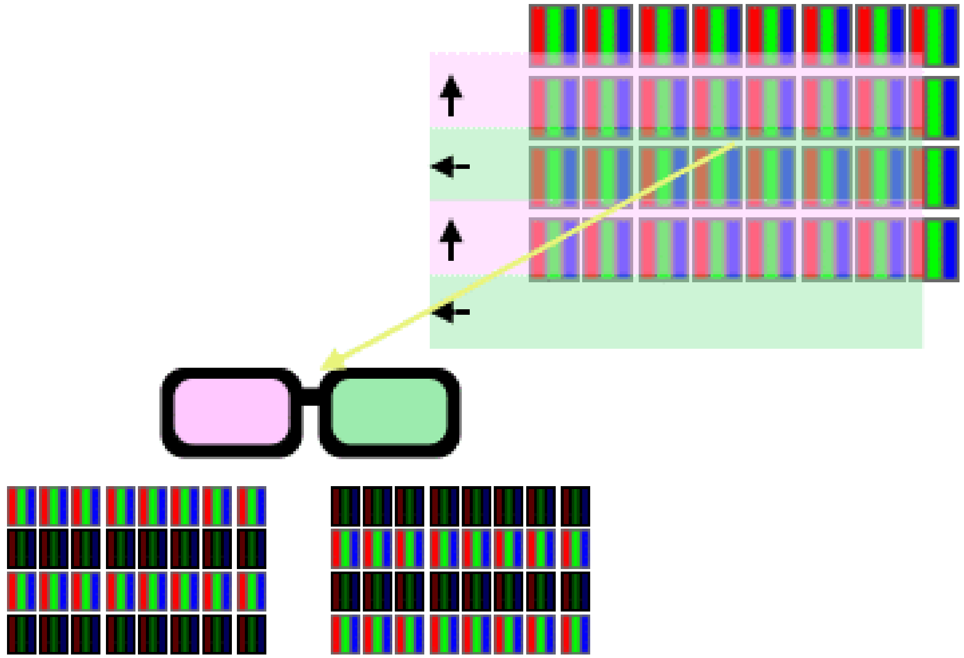
Polarization glasses

- How to display two polarized frames?

- Need accurate calibration so that the frames are aligned.
- Need non-depolarized screen.
- Cheaper glasses. Used in theater.

Polarization glasses



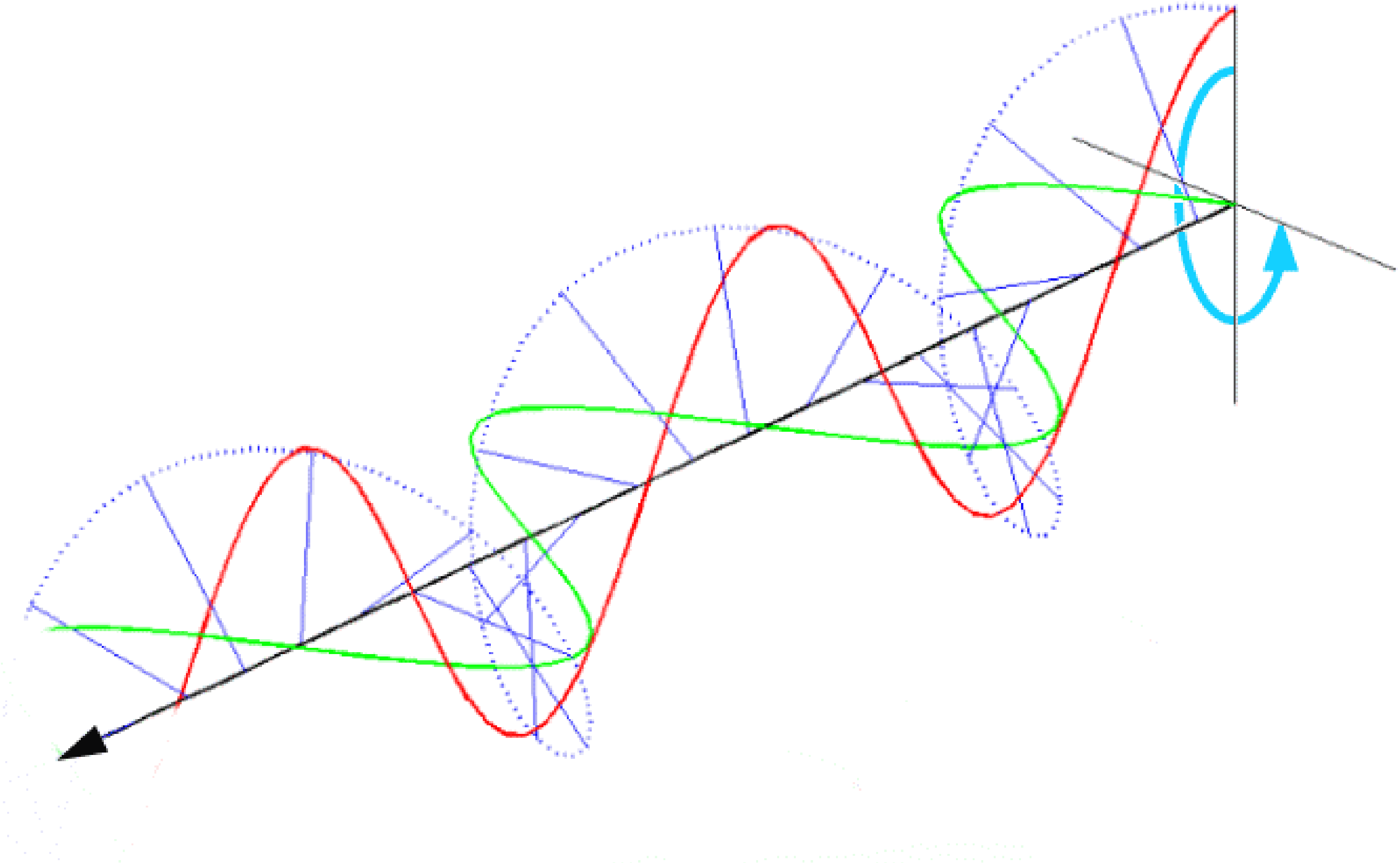


Problems with linear polarizer

DigiVFX

- Non-aligned viewers might see cross-talk

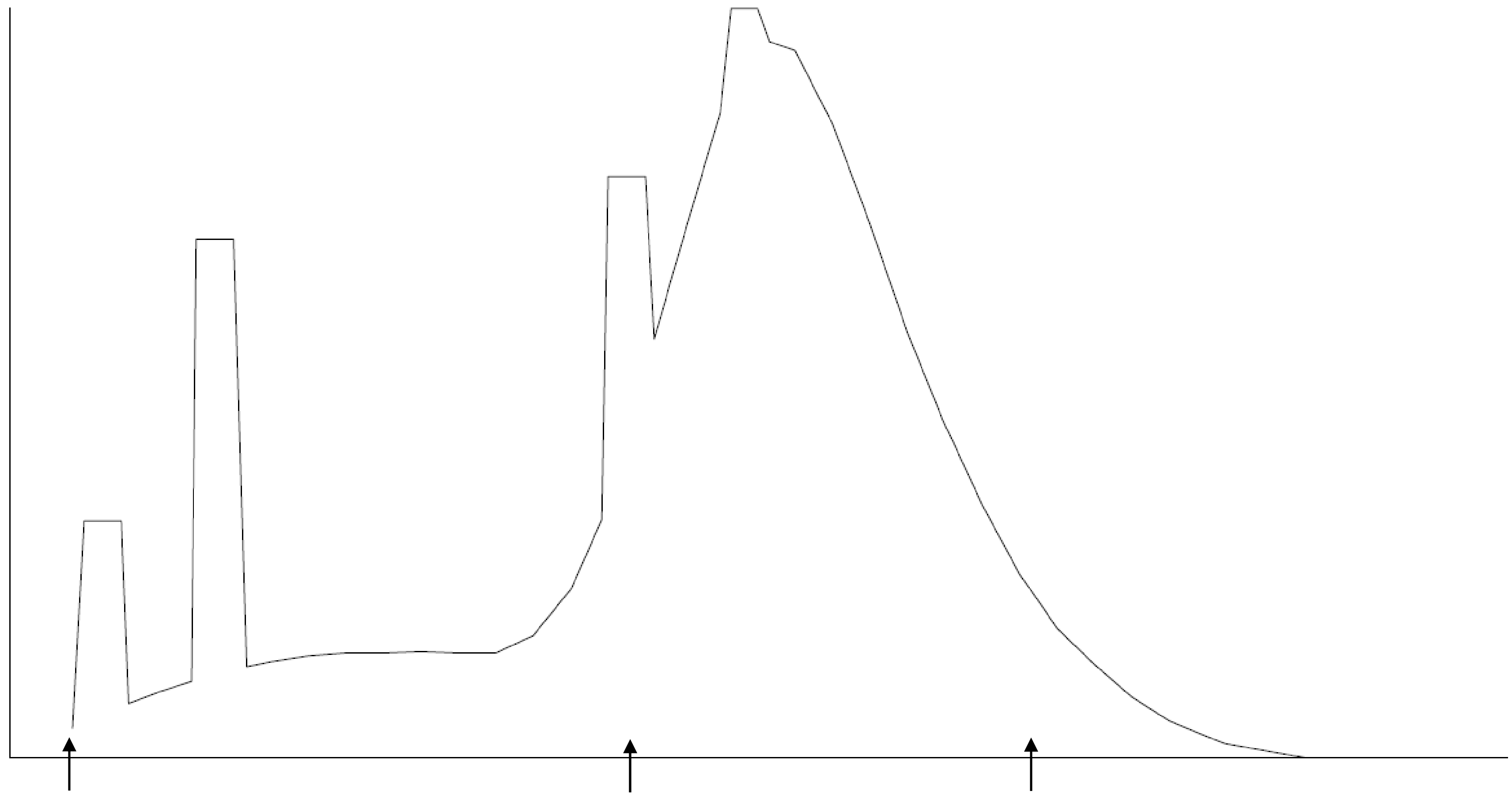
Circular polarizer



Spectral glasses

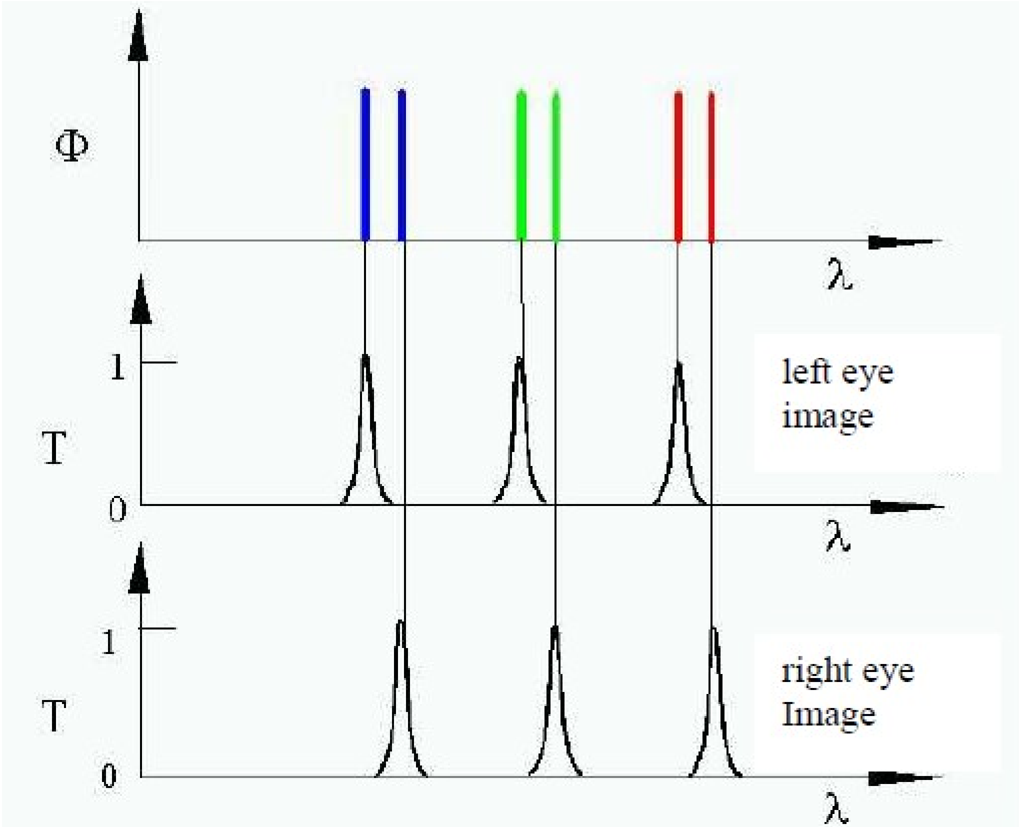
- Wavelength multiplexing. Infitec GmbH. Adapted by Dolby 3D digital cinema.
- Advanced anaglyph by dividing colors better.
- We will talk about human perception to colors first.

Spectral power distribution



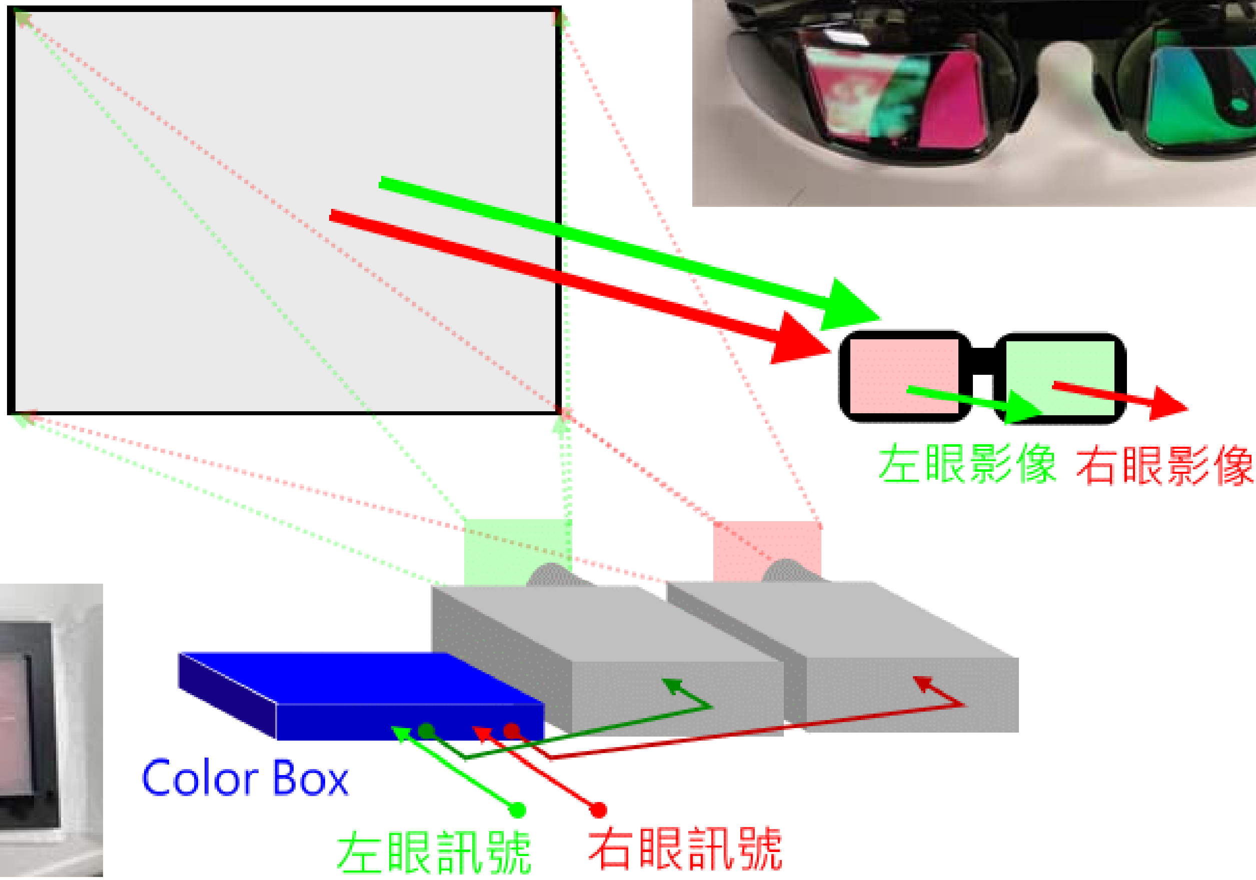
Spectral glasses

- Anyway, we learn that although light is a complex combination of electromagnetic waves of different wavelengths, it can be represented by three primary colors due to human perception.

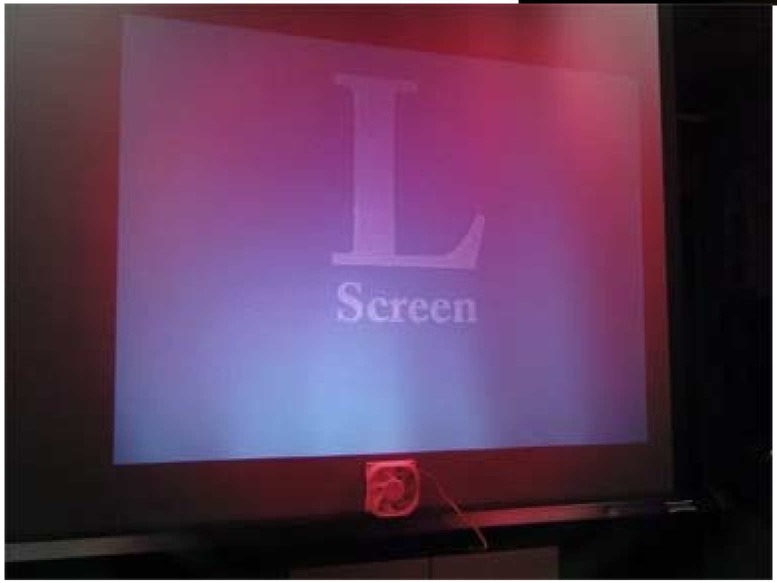


Spectral glasses

- Filters are added into projectors and glasses so that only lights of specific wavelengths can pass by. The color box adjusts colors.



Spectral glasses



Dolby 3D Digital Cinema

- Only requires one projector.

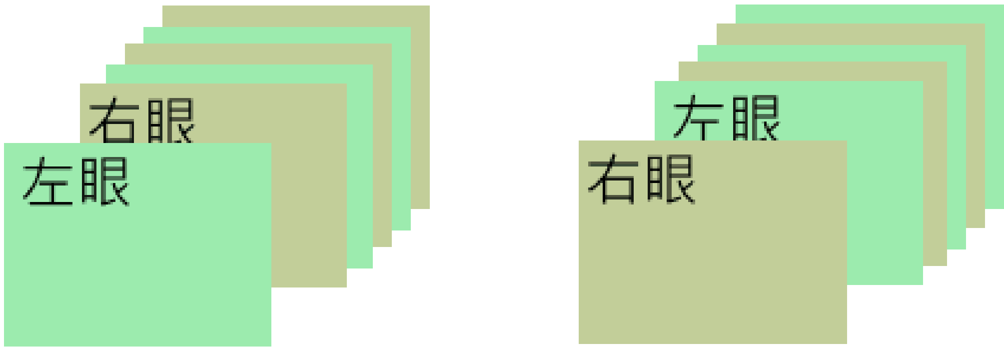
active hi-speed filter

Pros: no need for special screen

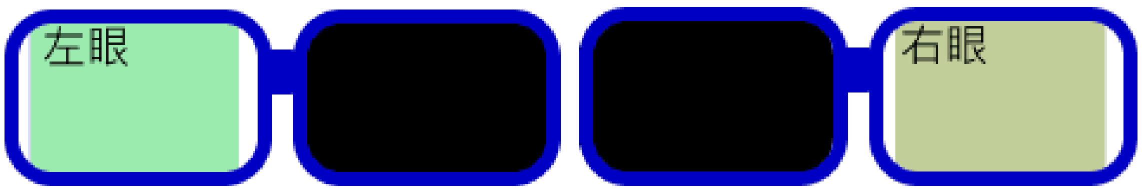
Cons: expensive filters
darker
specular

Shutter glasses

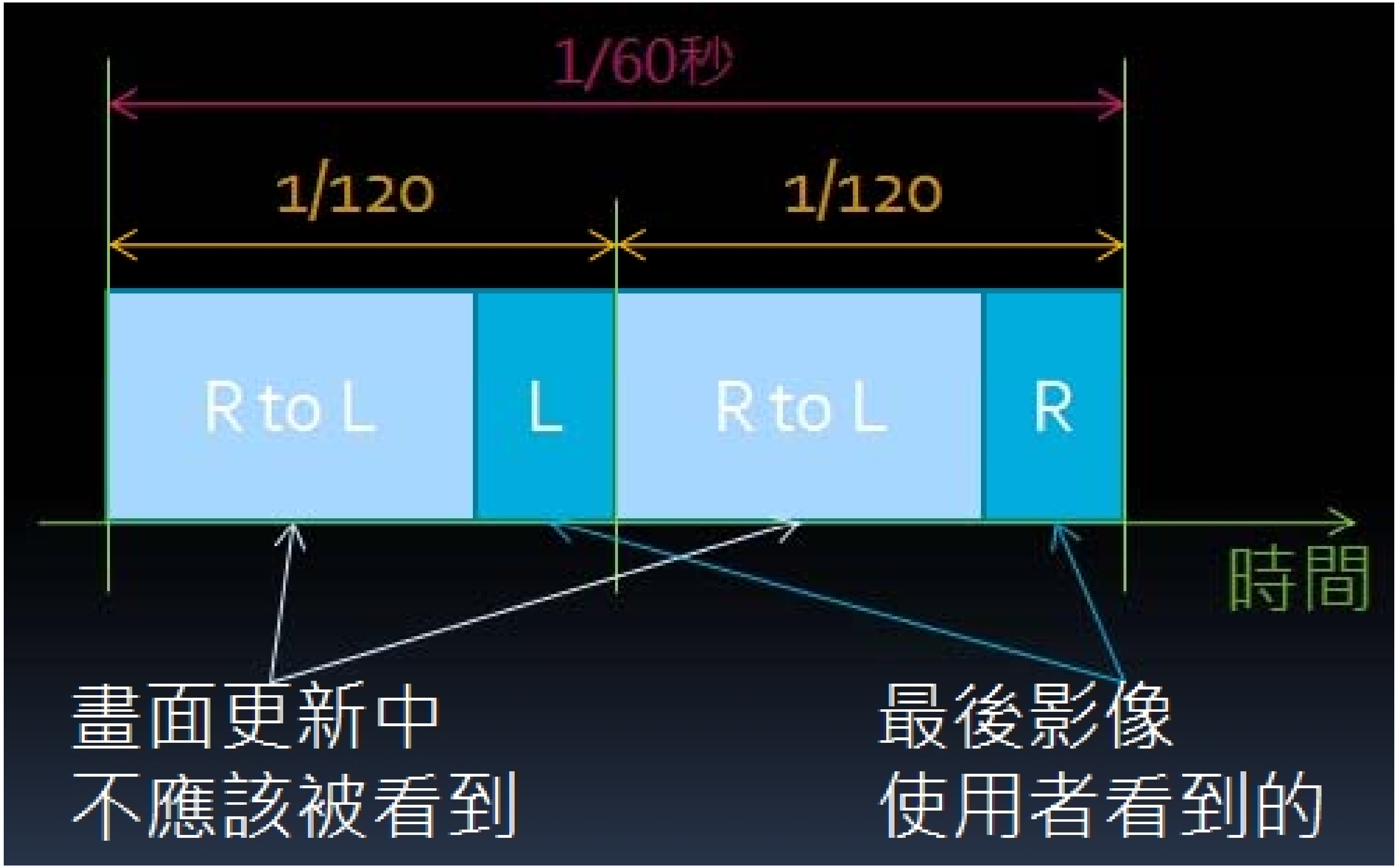
- Twice frequency (usually 120Hz).
- Liquid crystal. Needs to sync.
- Persistence of vision (視覺暫留)



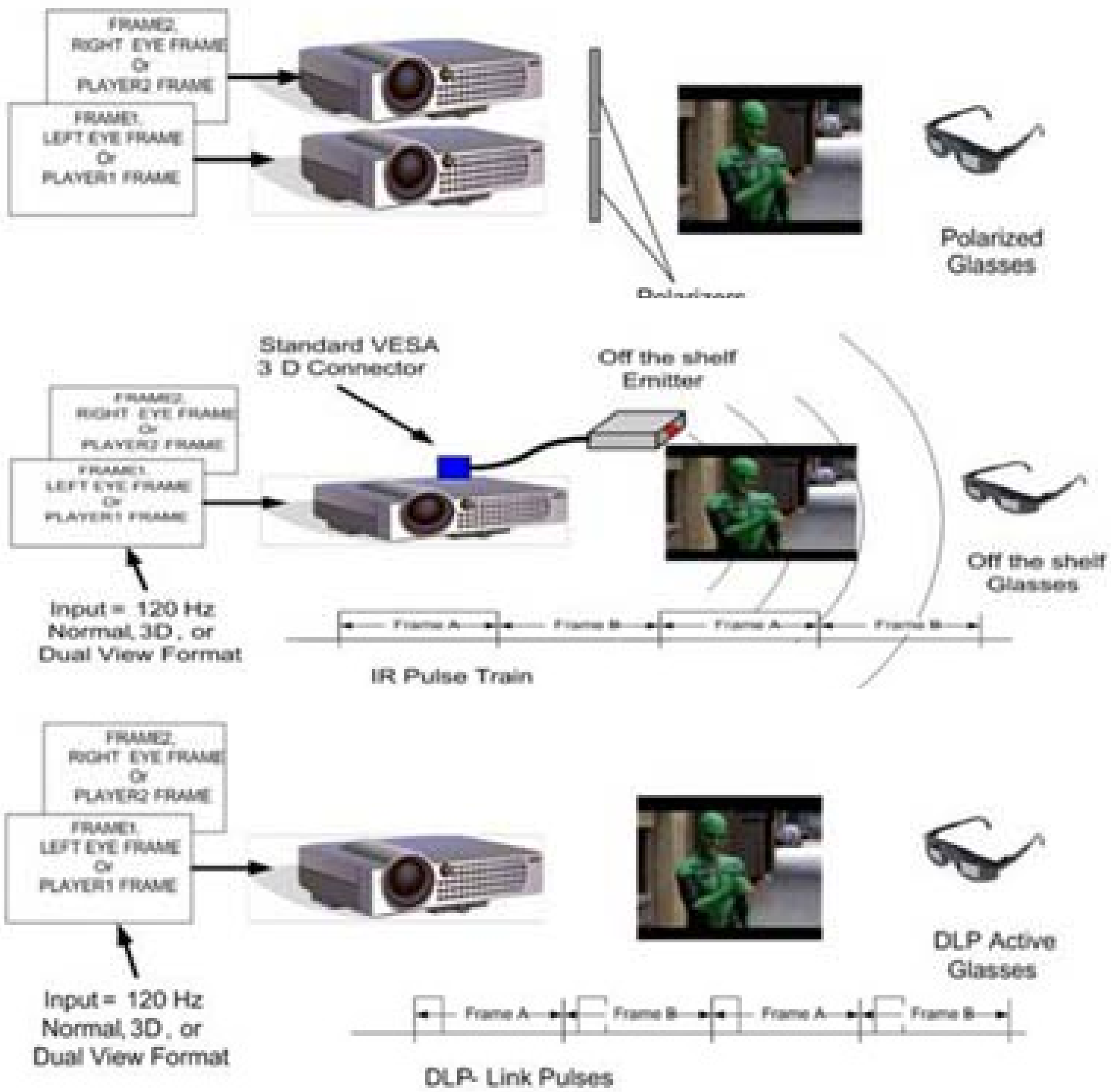
Pros: good 3D
Cons: need to sync
darker
expensive
not good for multi-user



Shutter glasses



TI DLP technology



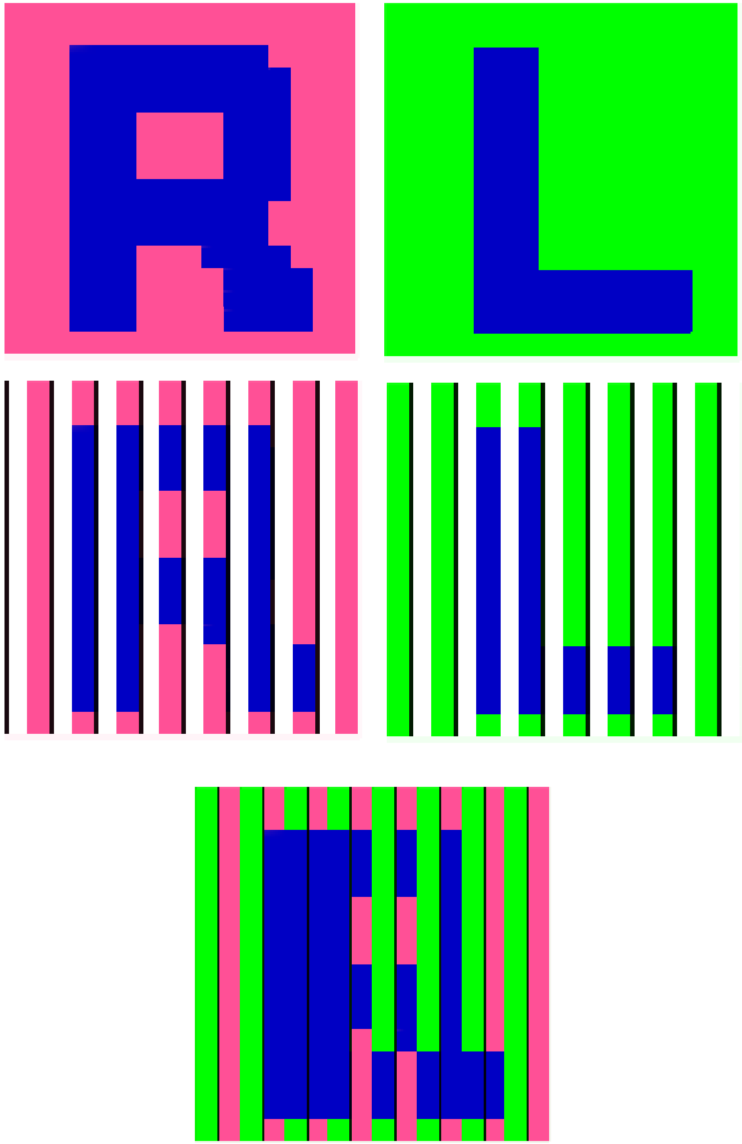
Head mounted displays

Pros: very good 3D
could be used with head trackers
Cons: expensive
heavy
closed
single-user

Autostereoscopic

- Control lights to radiate to specific directions by accurate optics calculation.
  - Spatial-multiplexed
  - Time-multiplexed

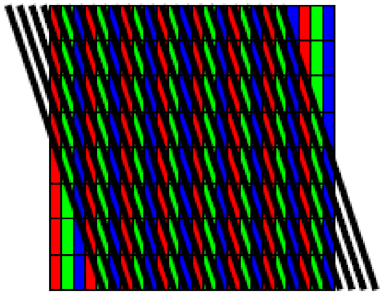
Spatial-multiplexed

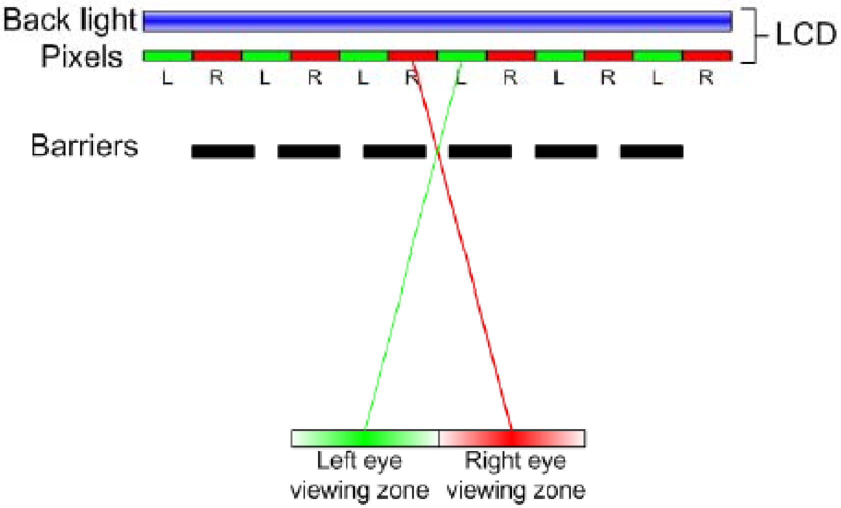


- The next question is how to let left eye see only the left image and right eye see only the right one.

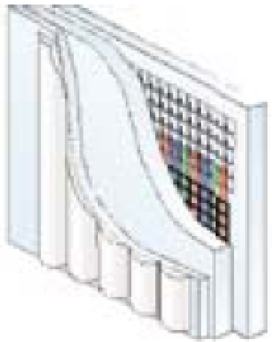
Autostereoscopic

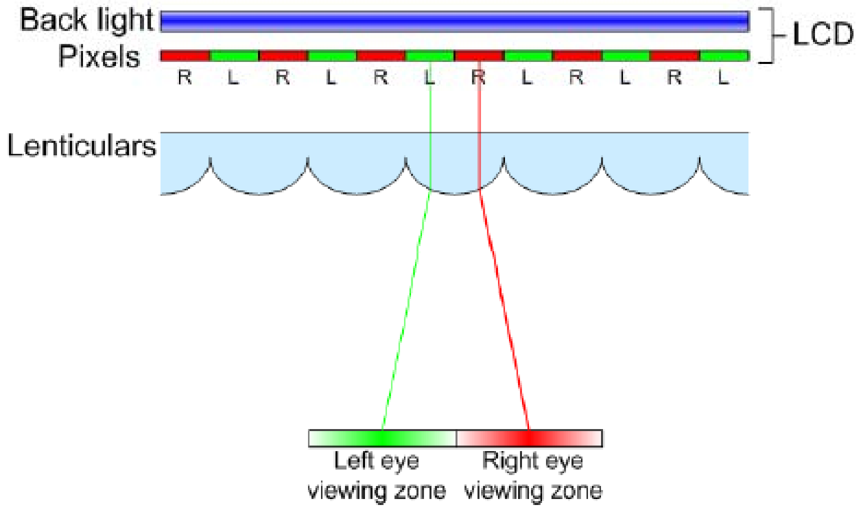
- Barriers(Slanted)



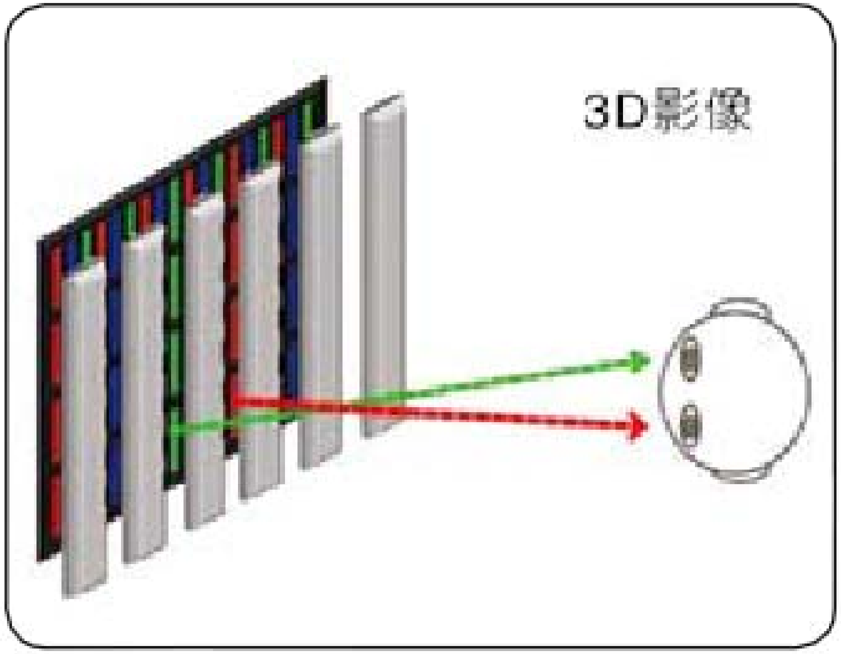


- Lenticulars

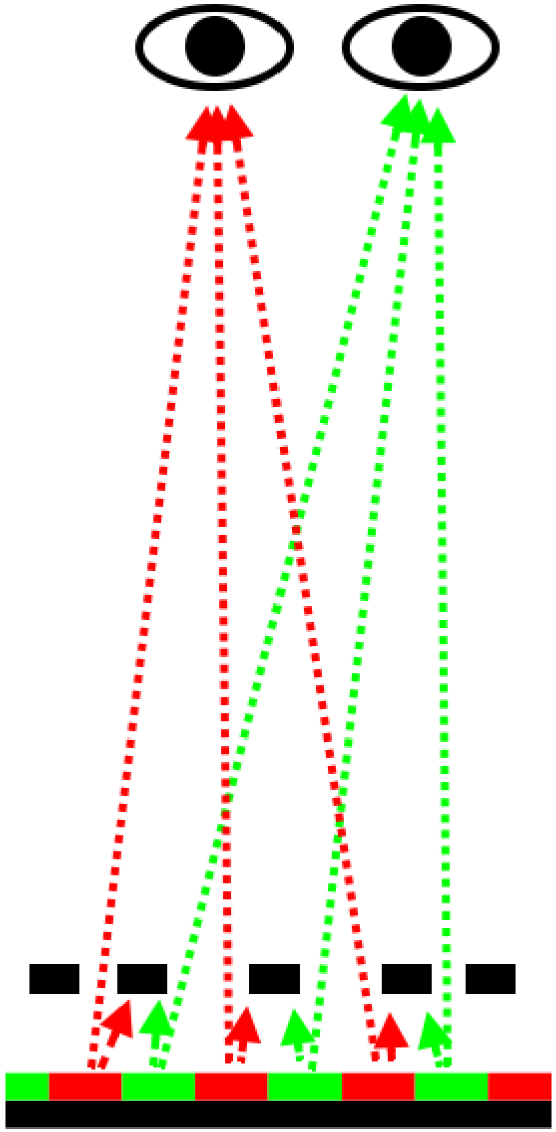




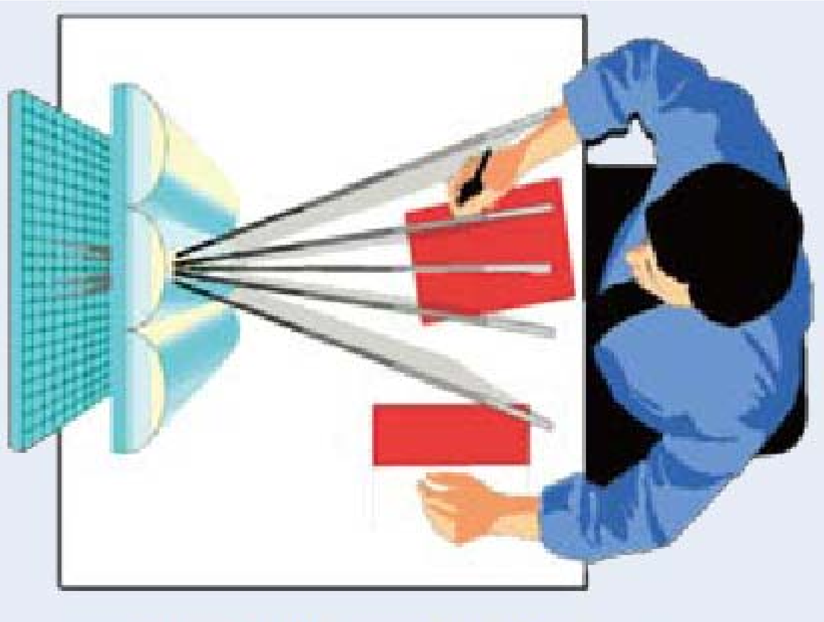
Barrier



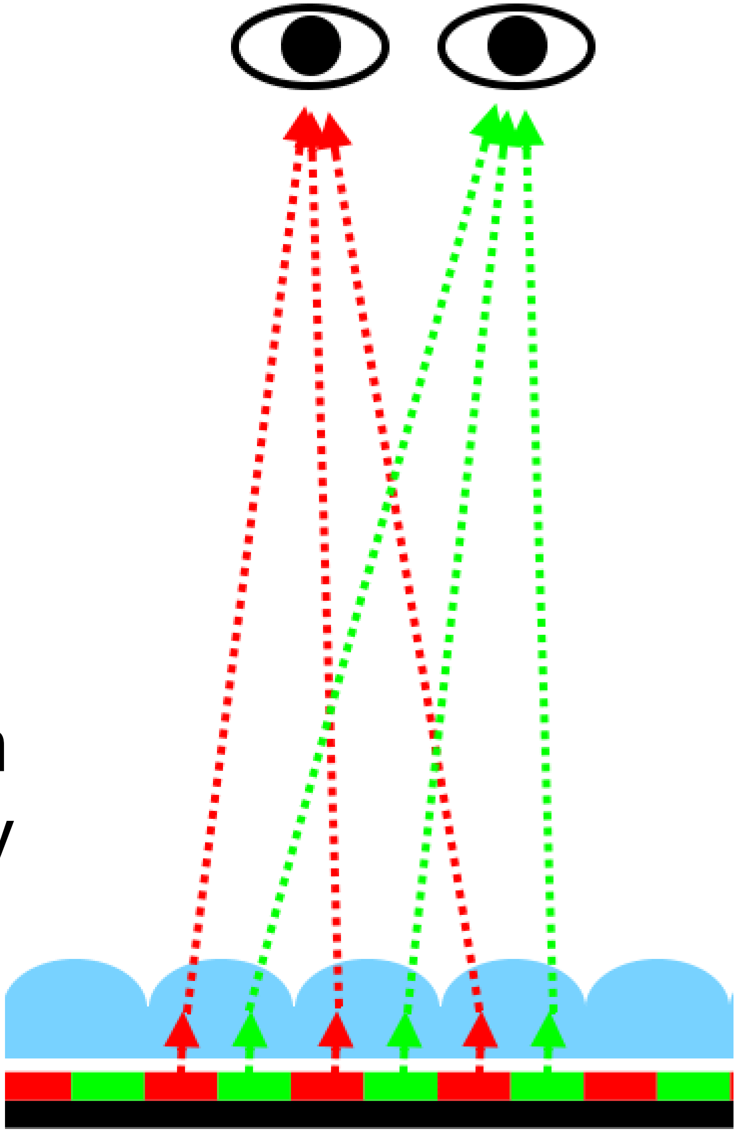
- LC barrier could switch between 2D and 3D display modes.



Lanticular



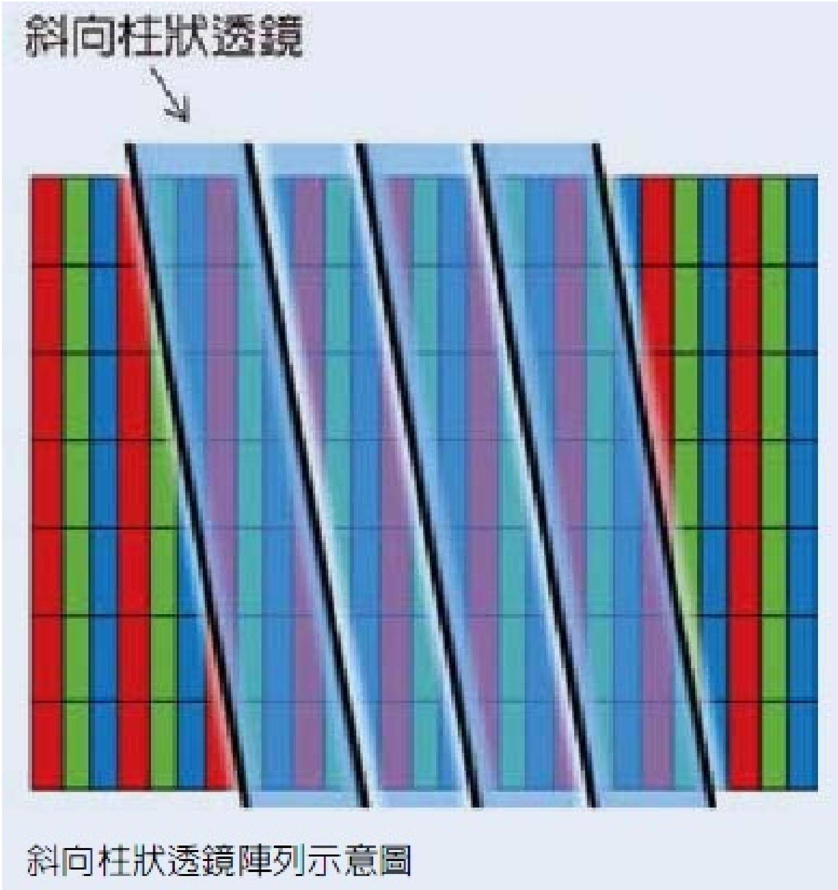
藉由柱狀透鏡陣列產生立體影像的示意圖



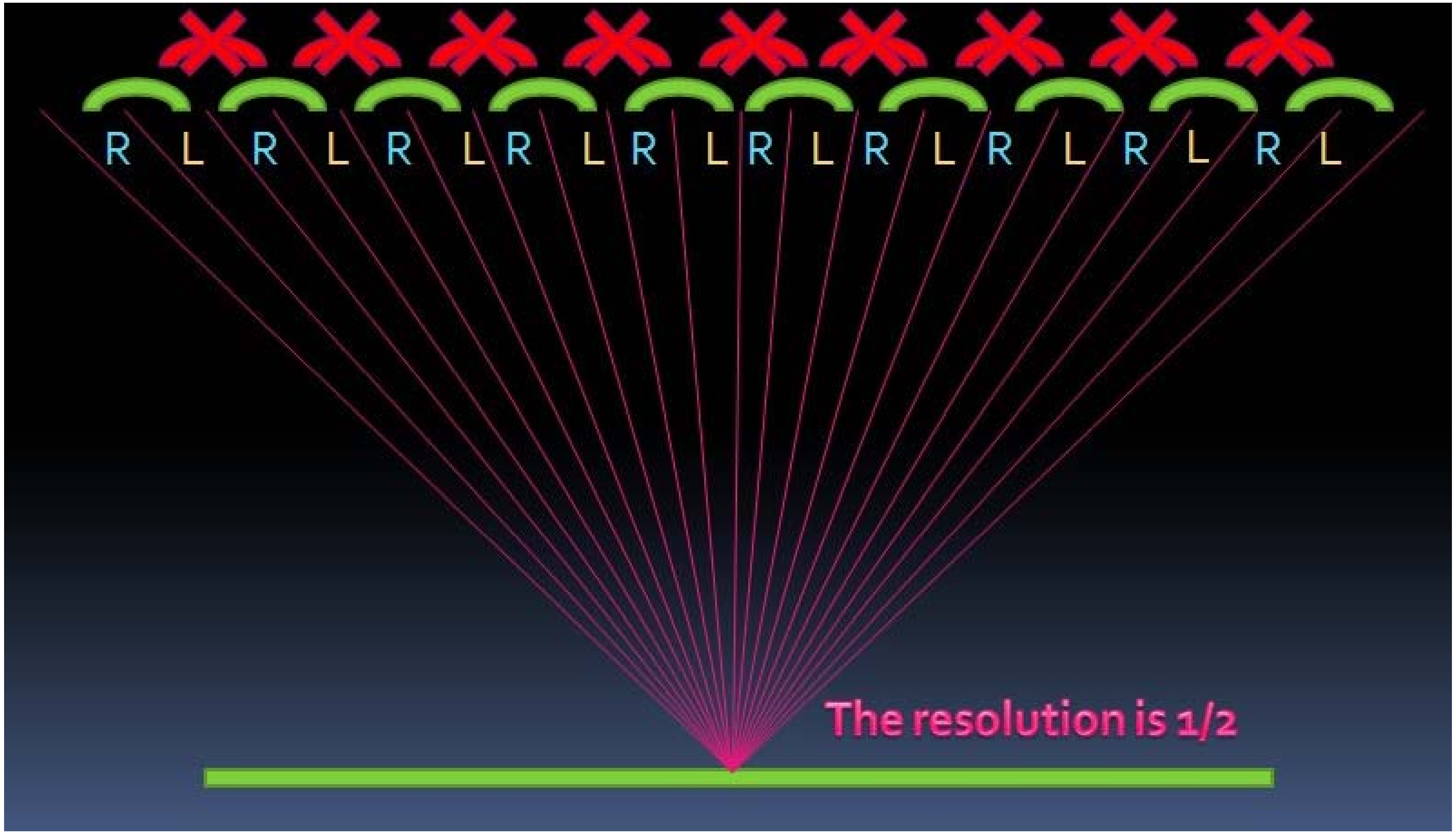
- It is also possible to switch between 2D and 3D display modes.

Slanted

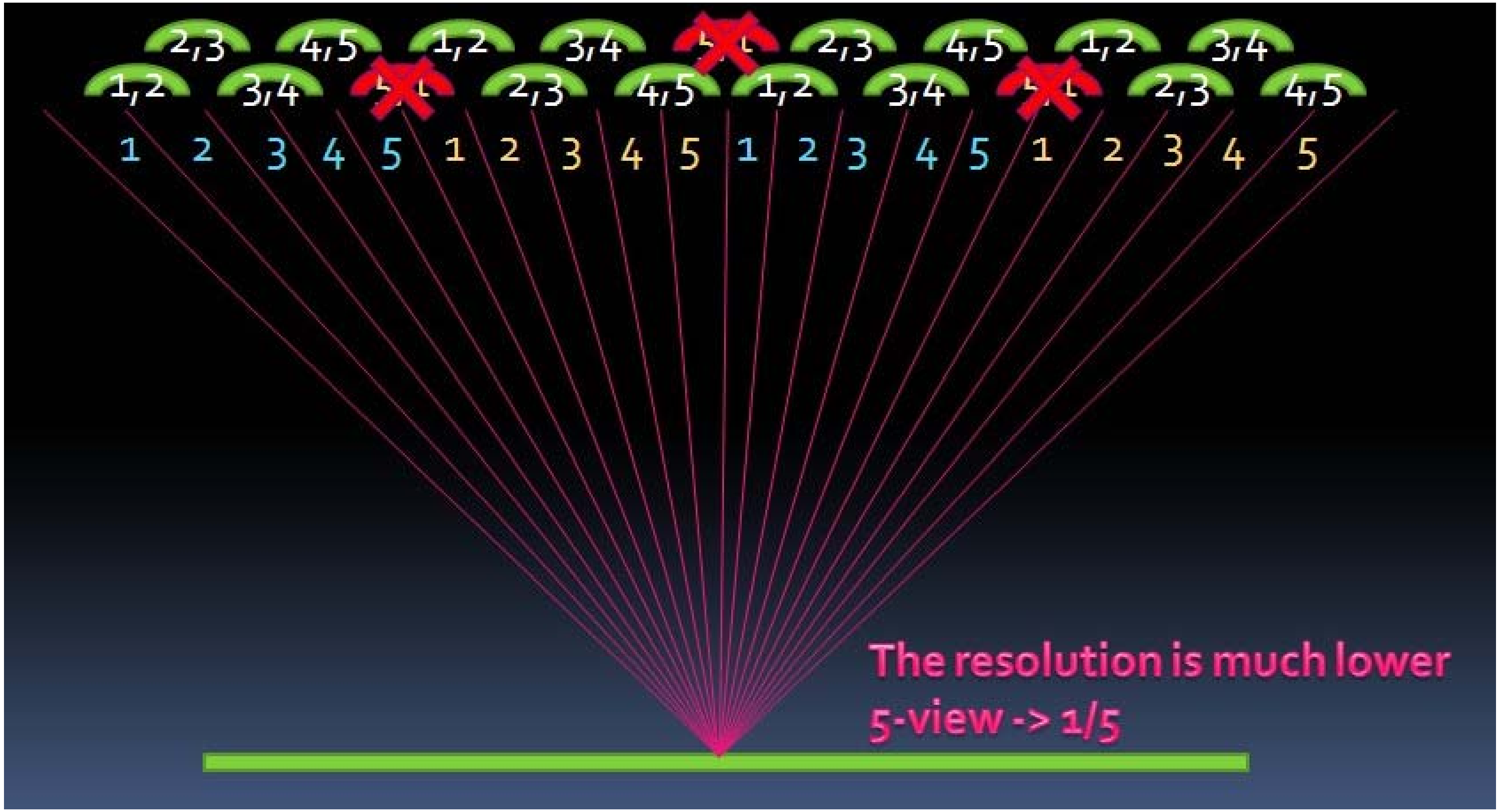
- To make more consistent horizontal and vertical aspect ratio.



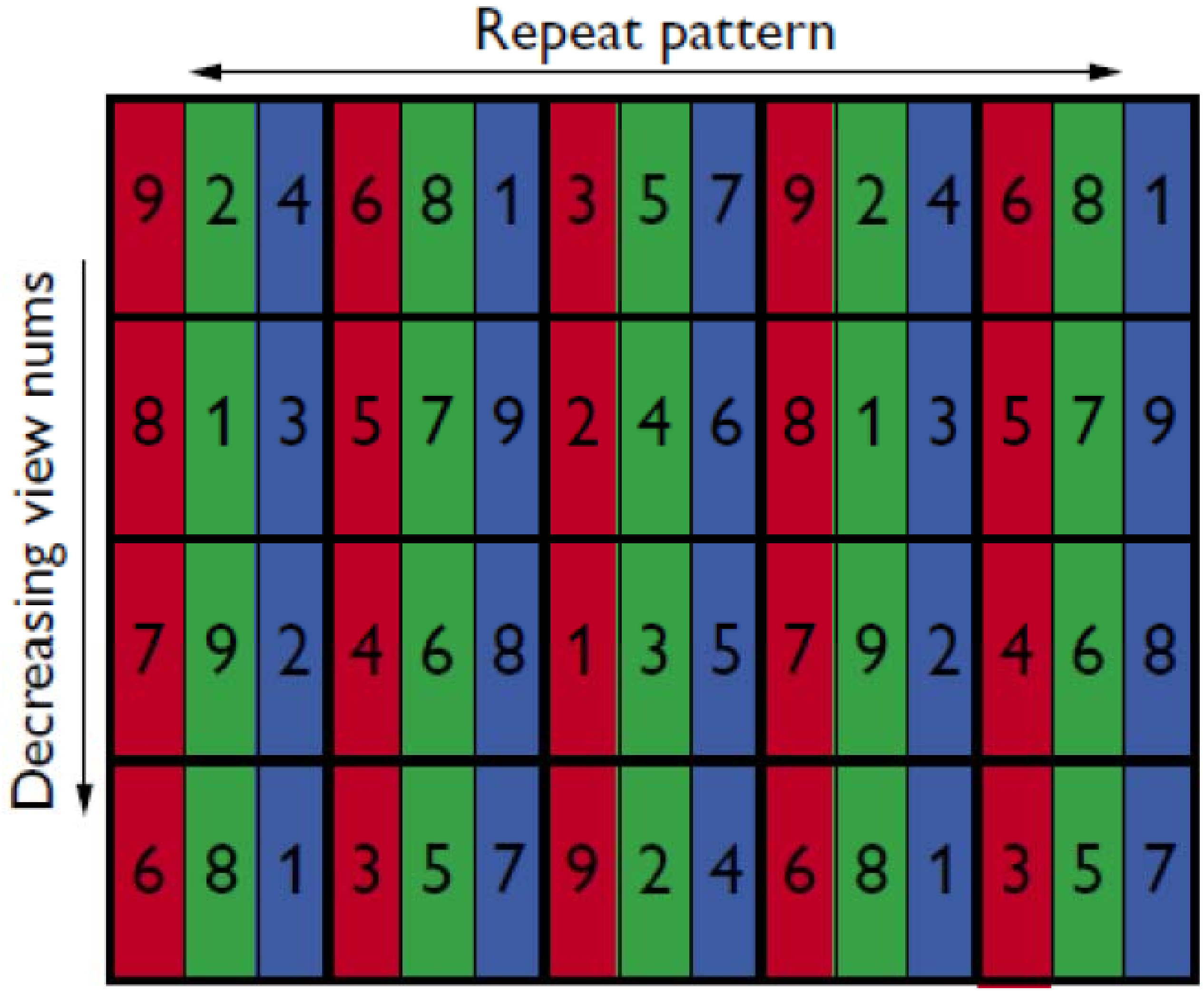
2-view



Multiple-view

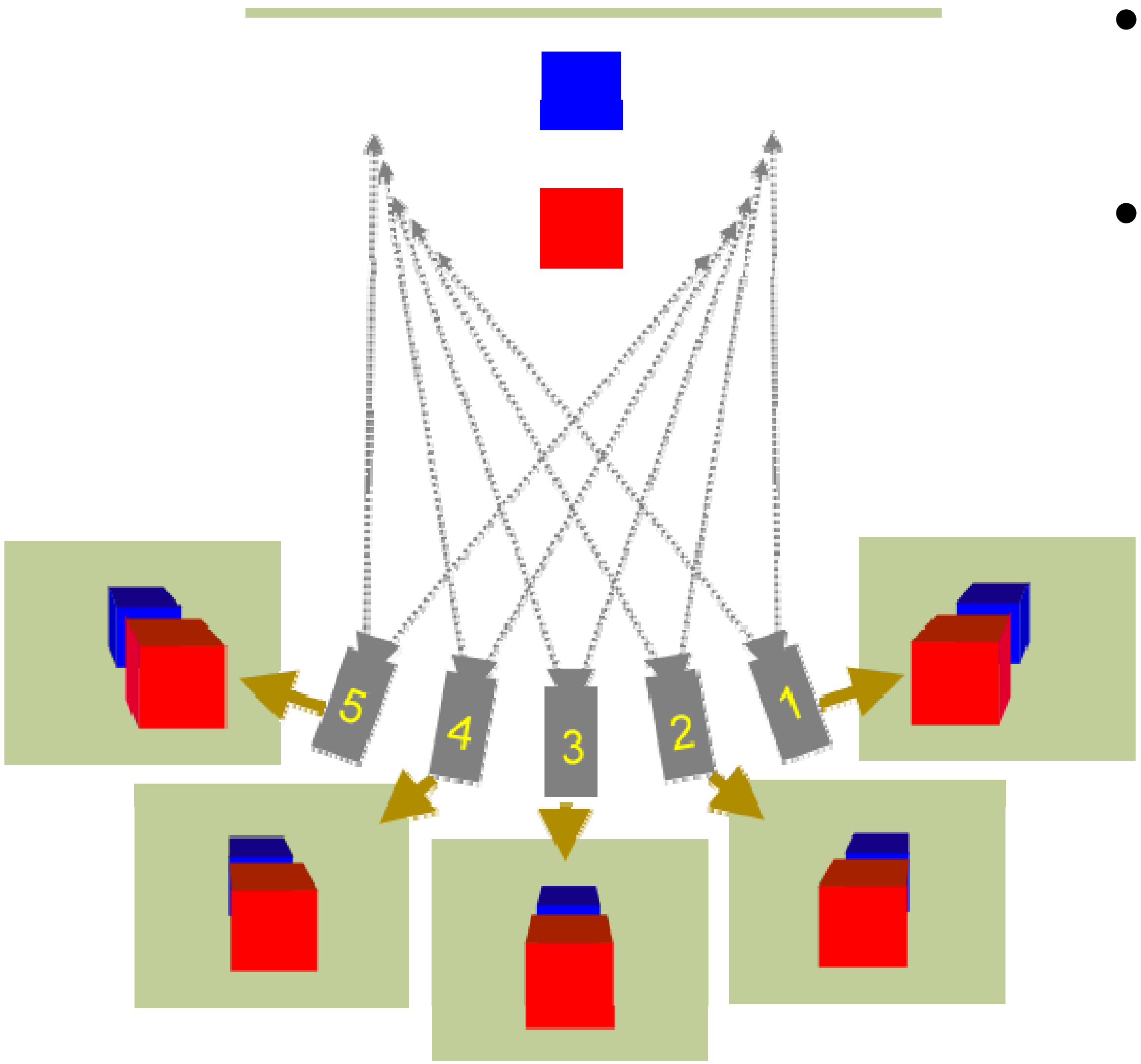


Philips 9-view format



View interleaving

Multiple-view

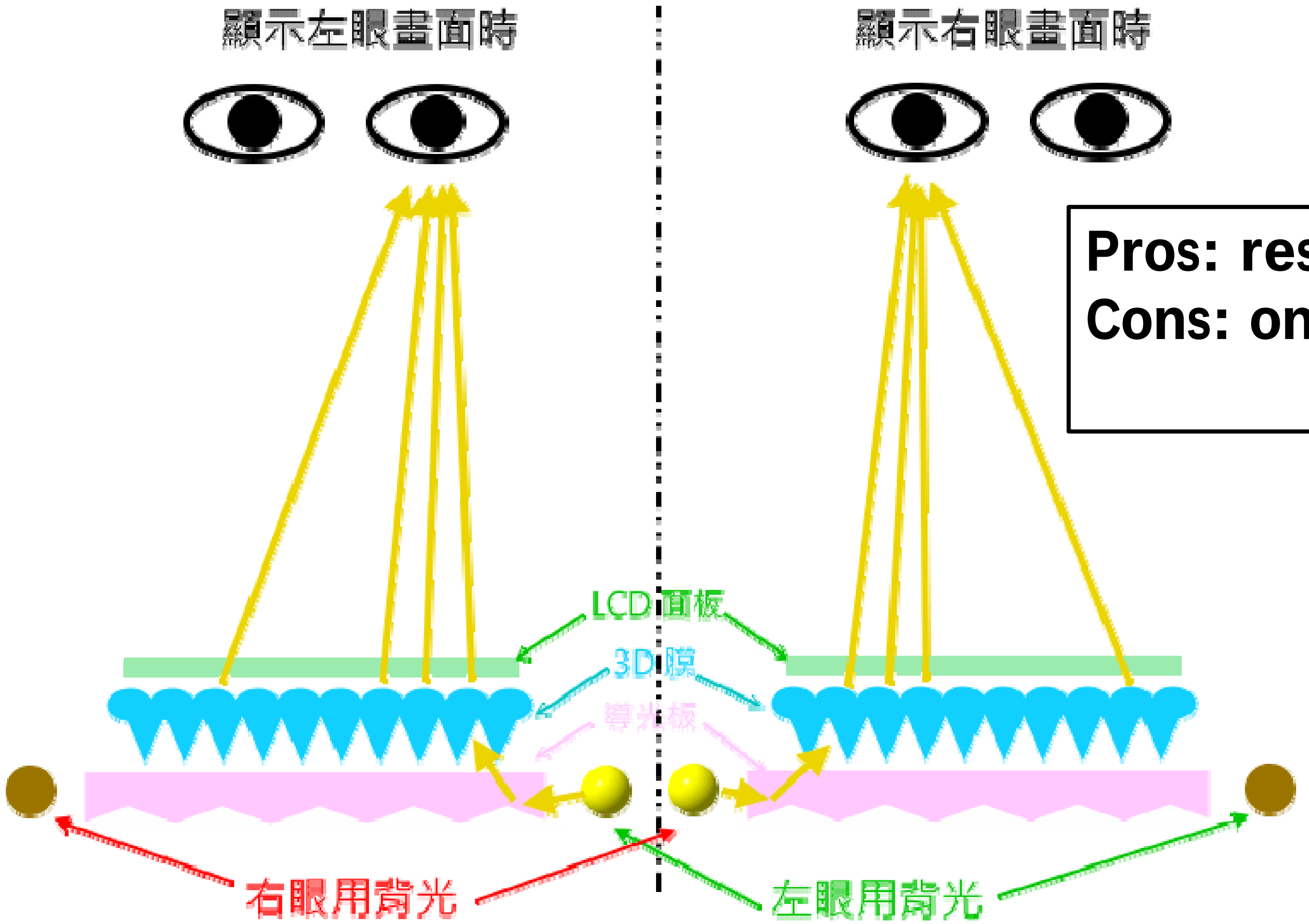


- Need more inputs.
- Reduced resolution.

Pros: no glasses
multi-user
Cons: location
bad 3D

Time-multiplexed

- Directional back light unit 3D film



Pros: resolution
Cons: only 2views

Comparisons

DigiVFX

3D顯示技術

- **戴眼鏡式 With glasses**
  - 優點：無視角問題
  - 缺點：需戴眼鏡
  - **快門眼鏡(Shutter glasses)**
    - 優點：3D品質最好
    - 缺點：硬體規格要求最高、輝度最低、閃爍
  - **偏光眼鏡(Polarization glasses)**
    - 優點：成本最低
    - 缺點：3D品質尚可
- **裸眼式 Without glasses**
  - 優點：不需戴眼鏡
  - 缺點：有視角問題
  - **Barrier**
    - 優點：技術最簡單、容易可2D/3D切換
    - 缺點：輝度、解析度下降
  - **Lenticular**
    - 優點：成本低、輝度較高
    - 缺點：解析度下降、不易可2D/3D切換

Common 3D formats

- Side-by-side
- Multi-view
- 2D+Z

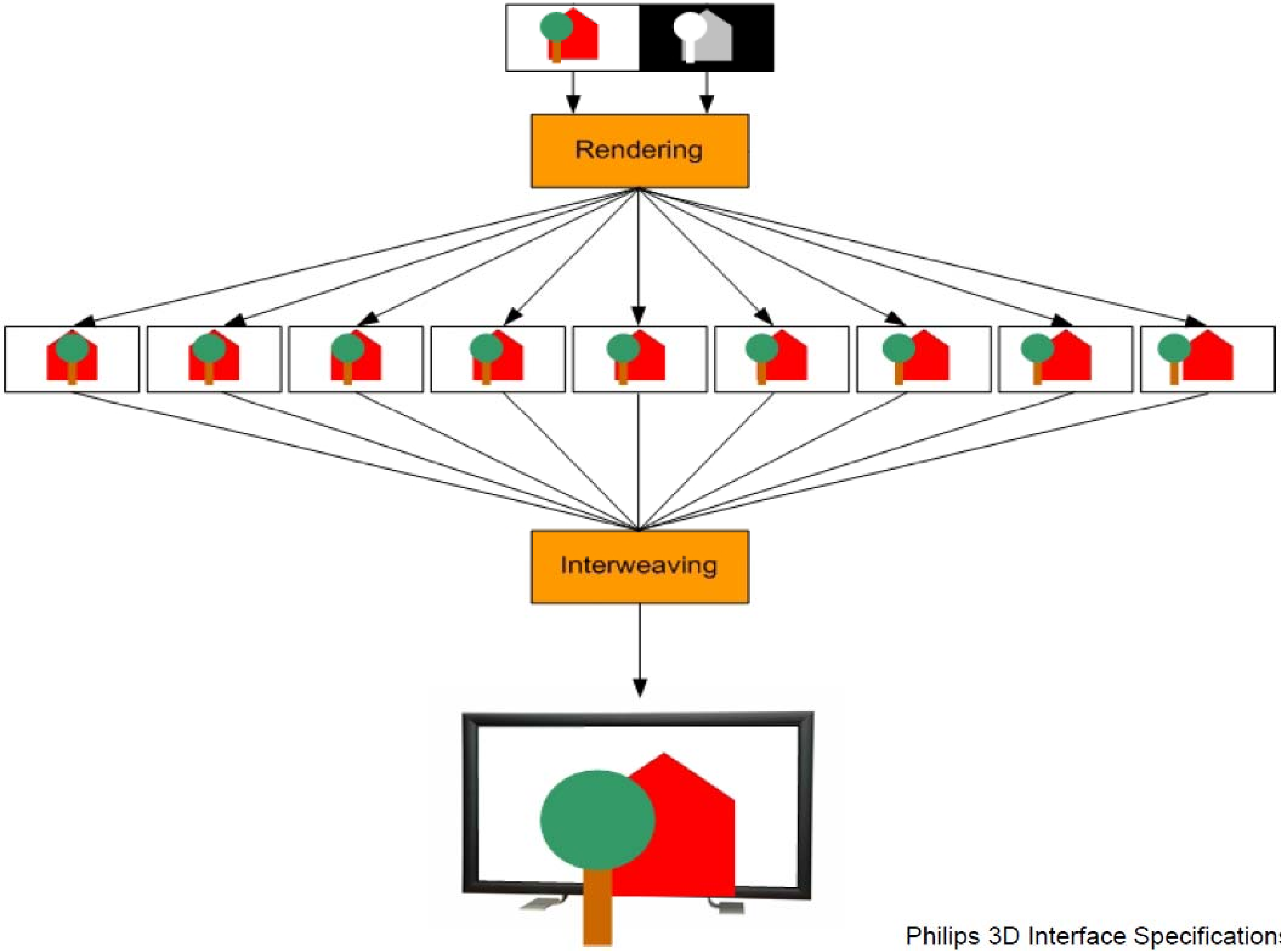
2-view

Side by Side

Multi-view

Newsight 8-View

2D+Z

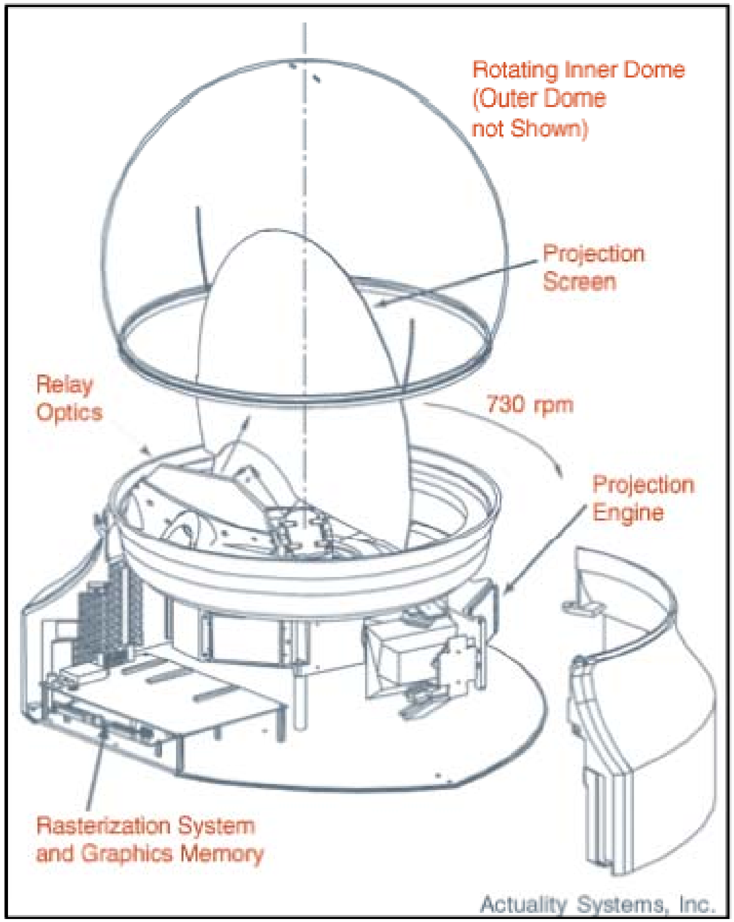


Philips 3D Interface Specifications White Paper

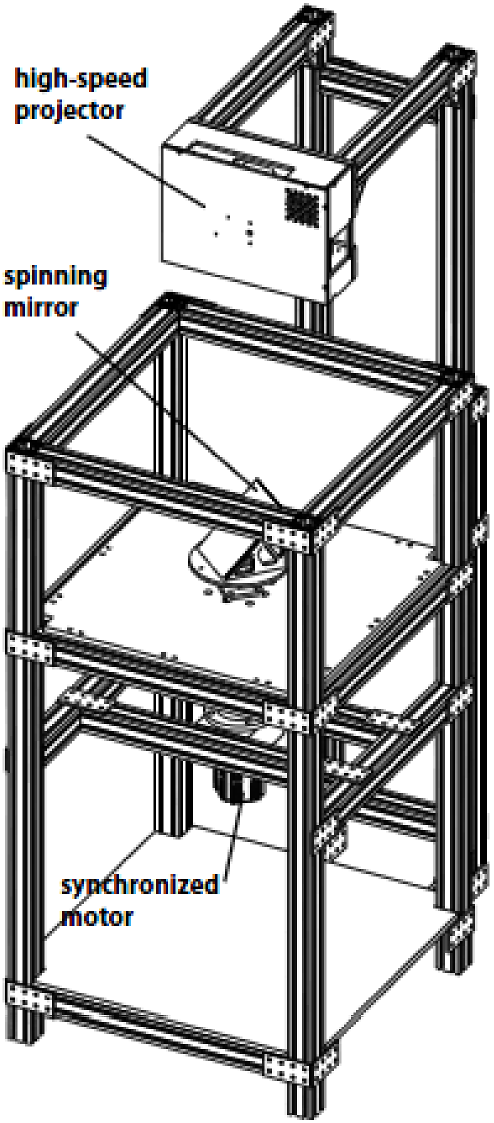
Volumetric displays

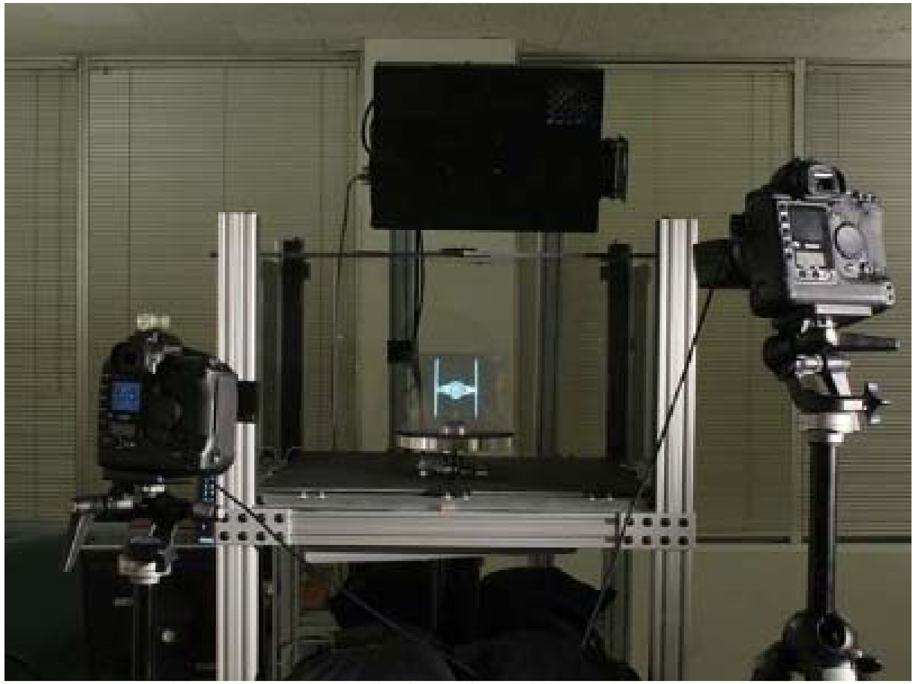
- Non-volumetric displays will make viewers fatigue after long viewing time because of inconsistency between focus and convergence.
- Volumetric displays will be better in this aspect but it is much more expensive and requires more data consumption (more views are required).
- Pros: good 3D, no glasses, multi-user
- Cons: often with limited size, suitable only for objects, not scenes

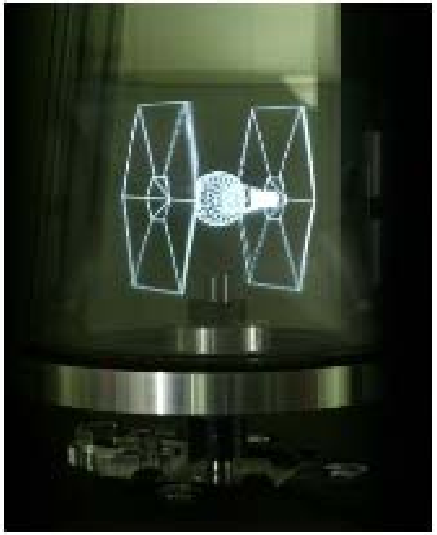
Actuality System



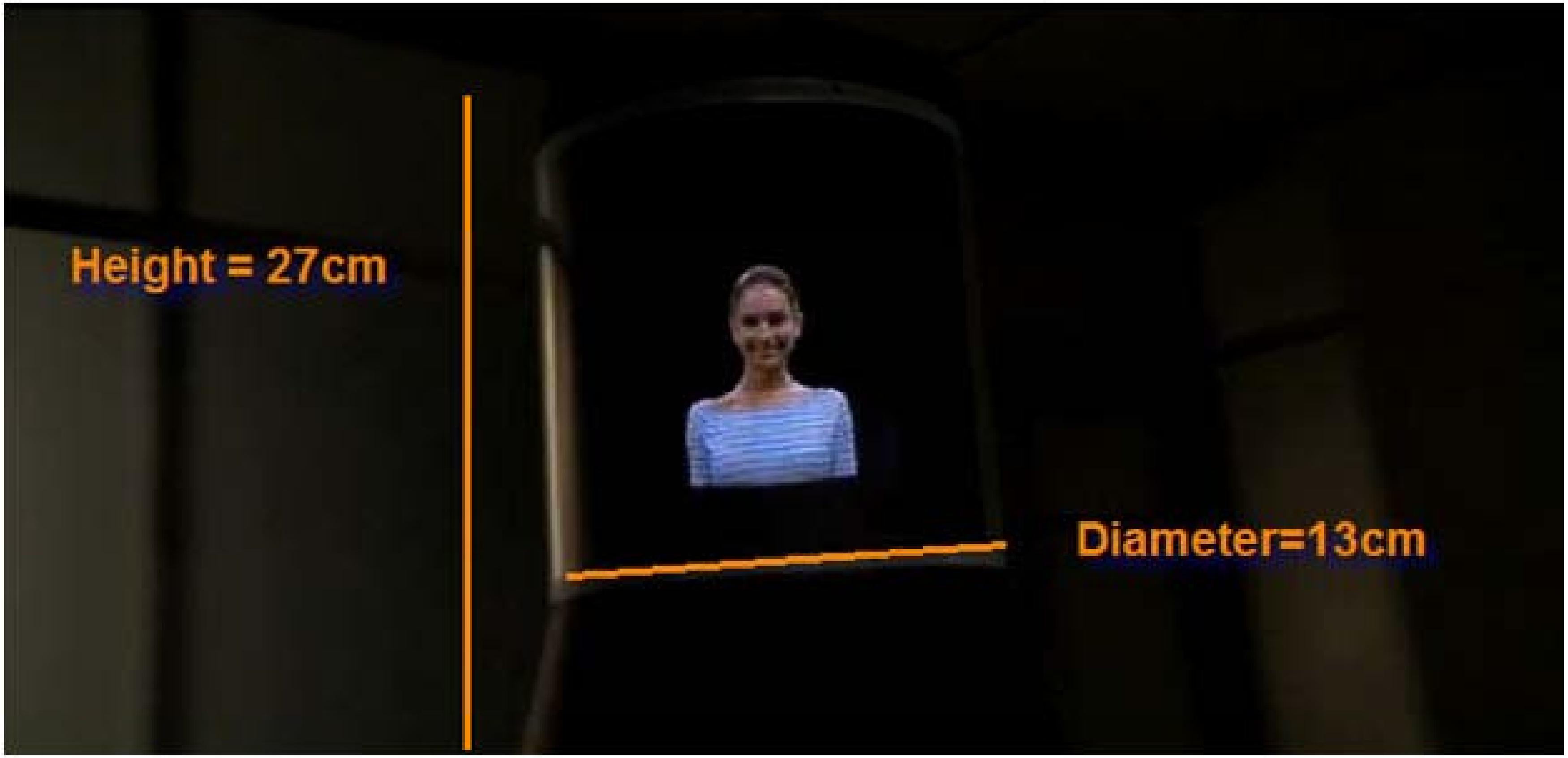
USC ICT







SONY RayModeler



The RayModeler is able to generate a true 3-D image with depth where a different proportionally correct view is visible from each side of the display.

Summary

- Many 3D displays will be produced in the coming years.
- Glass-equipped 3D display technology is very matured.
- Autostereoscopic displays need more time and will be used for advertisement first.
- 3D contents are the major bottleneck.
- But, 3D cameras are on the corner.

3D cinematography

Capture stereoscopic photos

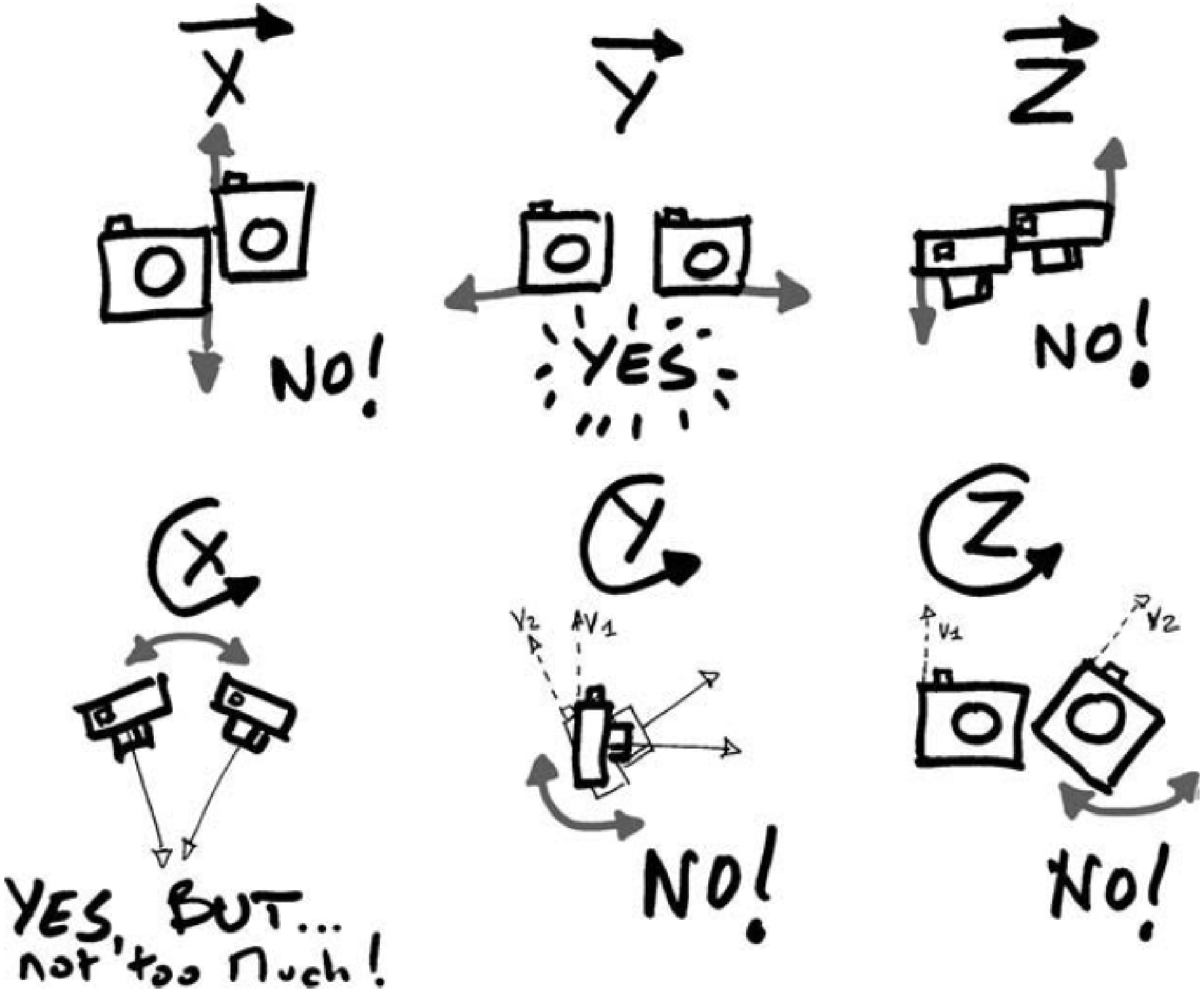
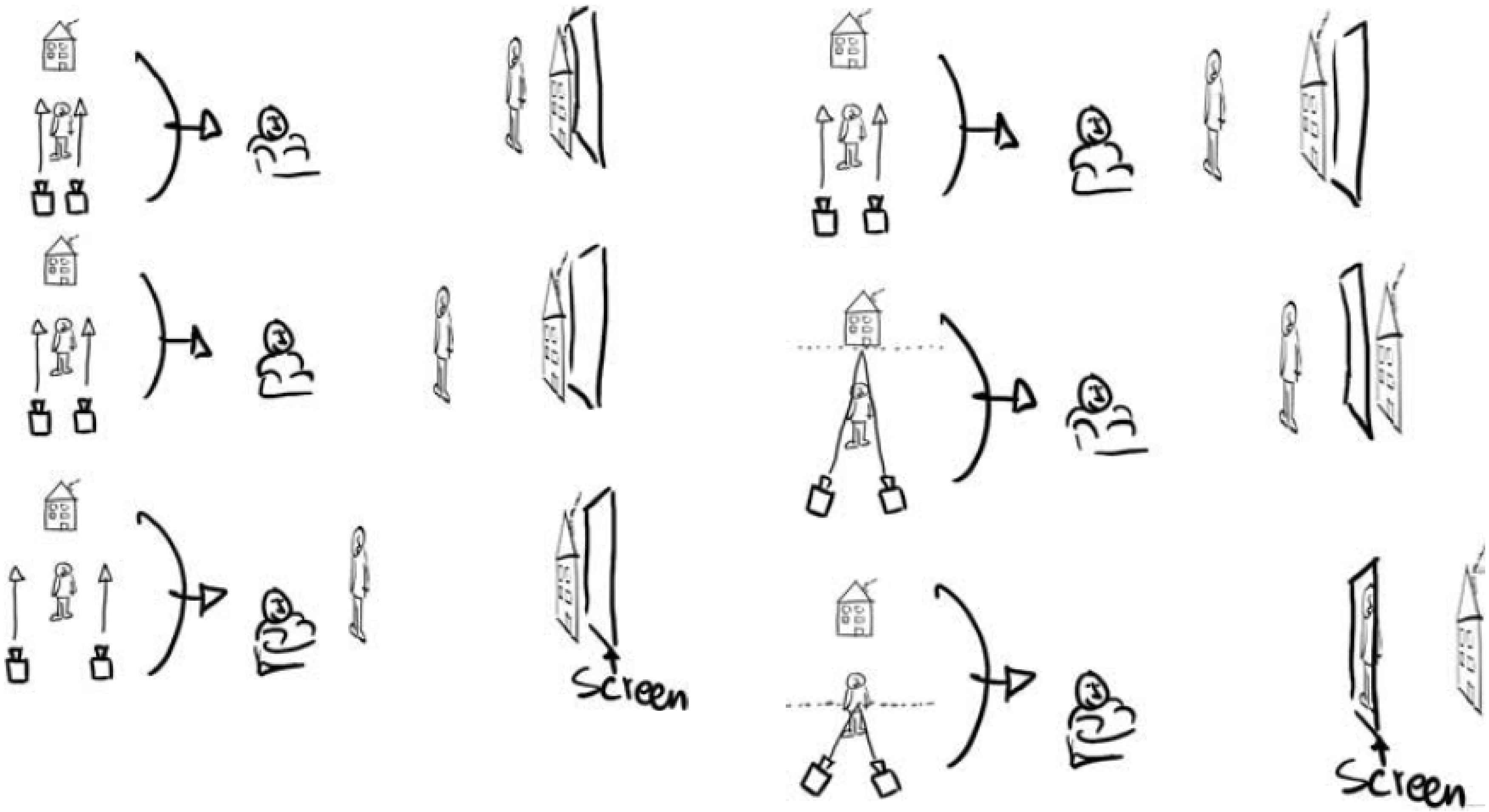


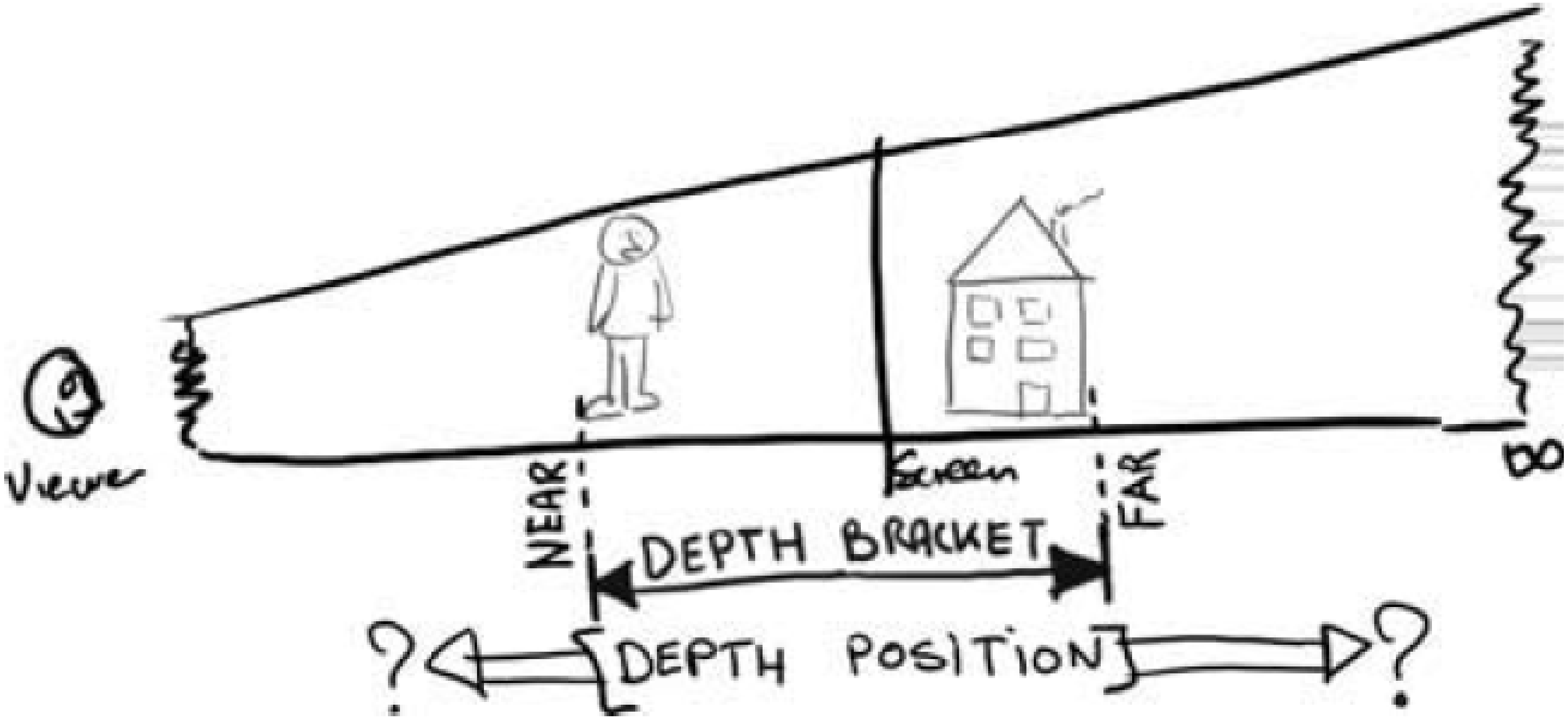
FIGURE 4.4
Of all six possible rotations and translations, only one translation and one rotation are appropriate in 3D.

Capture stereoscopic photos



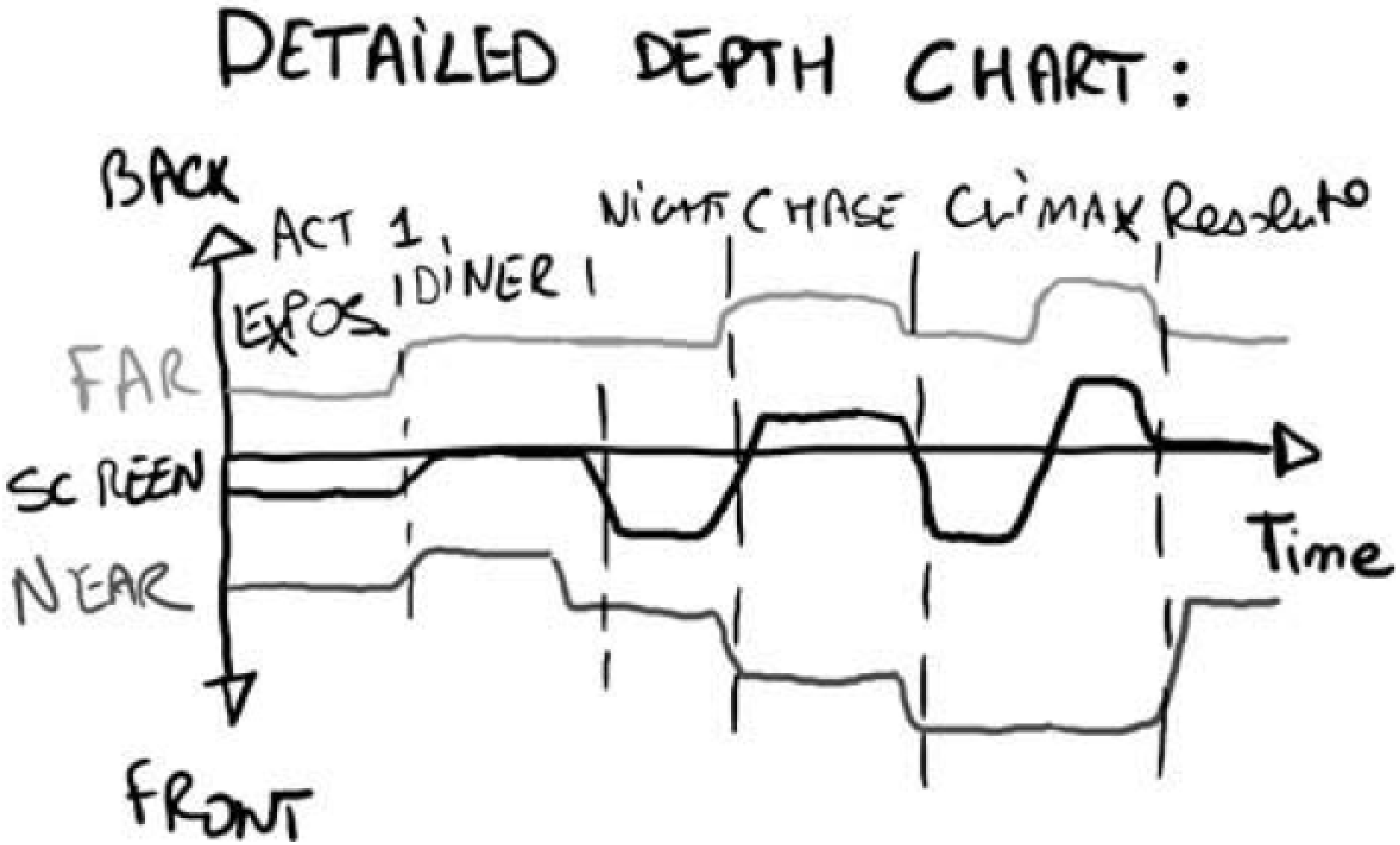
A few terms

- Depth bracket



A few terms

- Depth chart



Sources of visual fatigue

- The most important point to be considered in stereoscopic cinema.
- Symptoms: conscious (headache, tiredness, soreness of the eyes) or unconscious (perturbation of oculomotor system)
- Some even reported the case of an infant whose oculomotor wsystem was permanently disturbed by viewing a stereoscopic movie.

Sources of visual fatigue

- **Binocular asymmetry**: photometric or geometric differences between the left and right retinal images. Kooi and Toet experimentally measured threshiolds on various asymmetries that will lead to visual incomfort.
  - Human visual system is most sensitive to vertical binocular disparities.
  - 35 armin horizontal disparity range is quite acceptable and 70 arcmin disparity is too much to be viewed.

Sources of visual fatigue

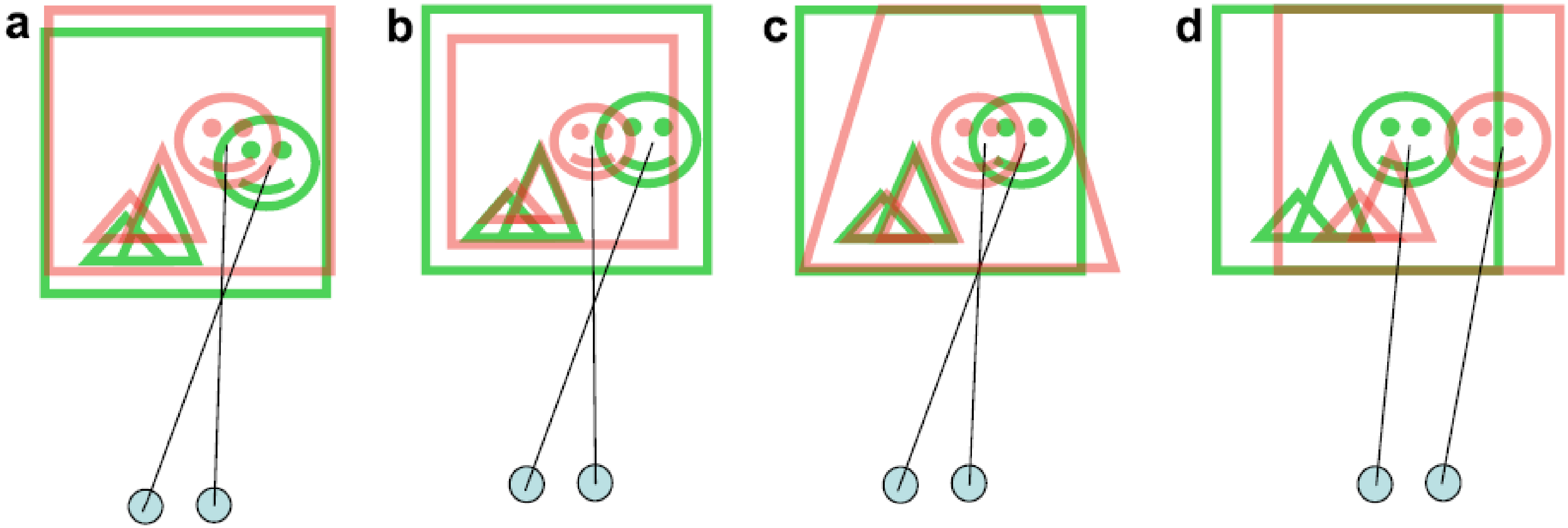


Table 4
Threshold values for each of the binocular image manipulations

Image manipulation	Threshold value
Rotations (1°)	> 1°
Other distortions	
Overall magnification	2.5%
Trapezoid	> 1PD
Meridional horizontal	> 3%
Meridional vertical	< 3%
Shifts	
Horizontal	Between 2 and 3PD
Vertical	< 1PD
Stereo images	Between 2× and 4× hyper-stereo
Crosstalk	
Low disparity	> 5%
High disparity	5%
Filter	
Contrast difference	Between 25 and 50%
Luminance difference (–25%)	> 25%
Black and white representation	OK
Gaussian blur	< 1 pixel
Local luminance	Between 4 and 8 bit digitization
Color asymmetry	Less than red/green separation

Sources of visual fatigue

DigiVFX

- **Crosstalk** (crossover or ghosting): typical values for crosstalk are 0.1-0.3% with polarization-based systems, and 4-10% with LCD shutter glasses. It could be reduced by a preprocess called ghost-busting.
- **Breaking the proscenium rule** (breaking the stereoscopic window): a simple solution is to float the window

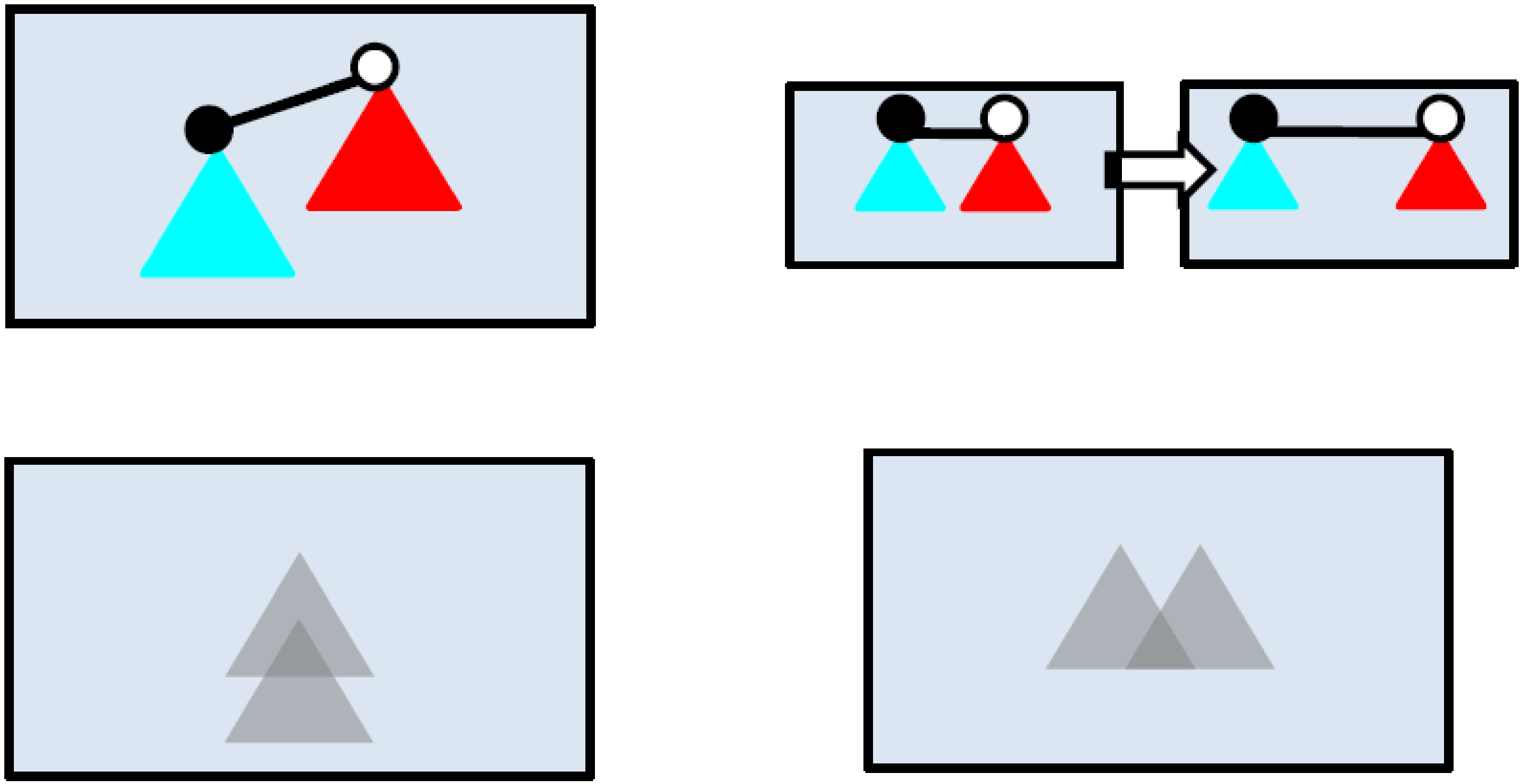
Sources of visual fatigue

DigiVFX

- **Horizontal disparity limits**: the eyes should not diverge and there is a certain limit below which human visual system can fuse
- **Vertical disparity**: causes torsion motion of the ocular globes and is only tolerable for short time intervals.
- **Vergence-accommodation conflicts**: focus distance of the eyes is not consistent with their convergence angle. They happen very often for stereoscopic displays and could be relaxed by using the depth of field of the visual system.

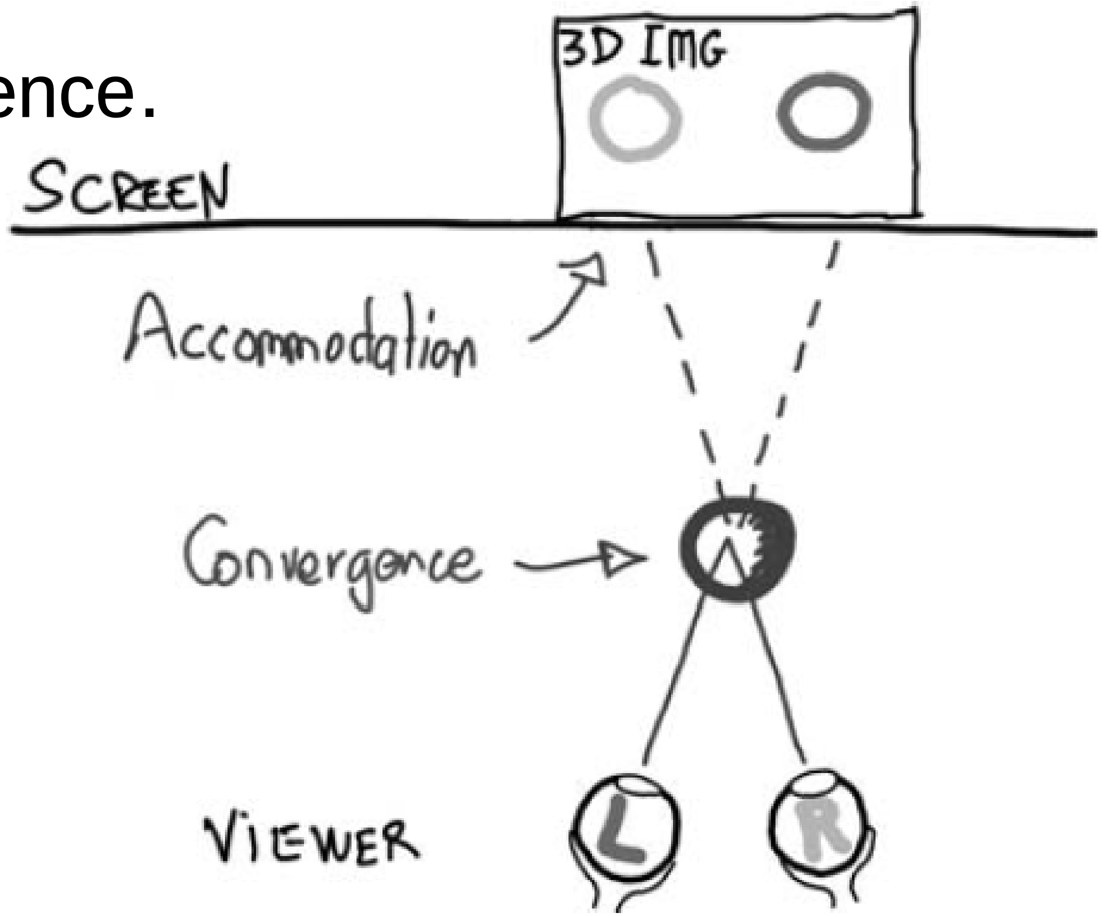
Stereopsis

- Stereopsis could be broken for the following



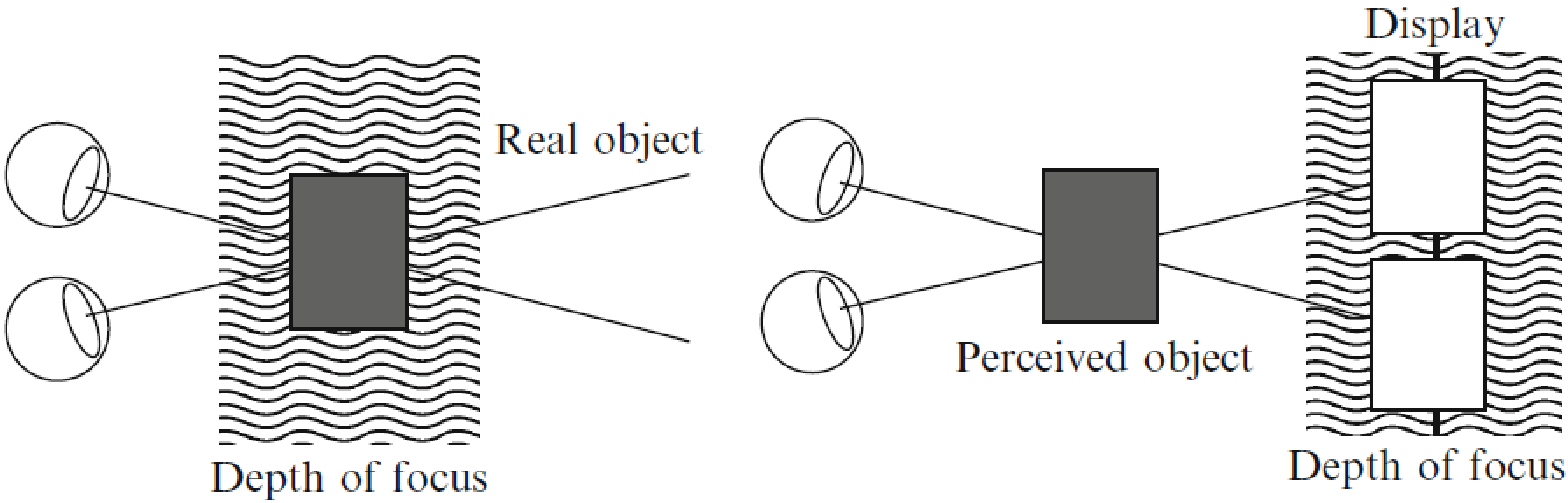
Vergence-accommodation

- Vergence, Convergence, divergence: the angle formed by the optical axis of the two eyes in binocular vision.
- Plane of convergence.



Vergence-accommodation

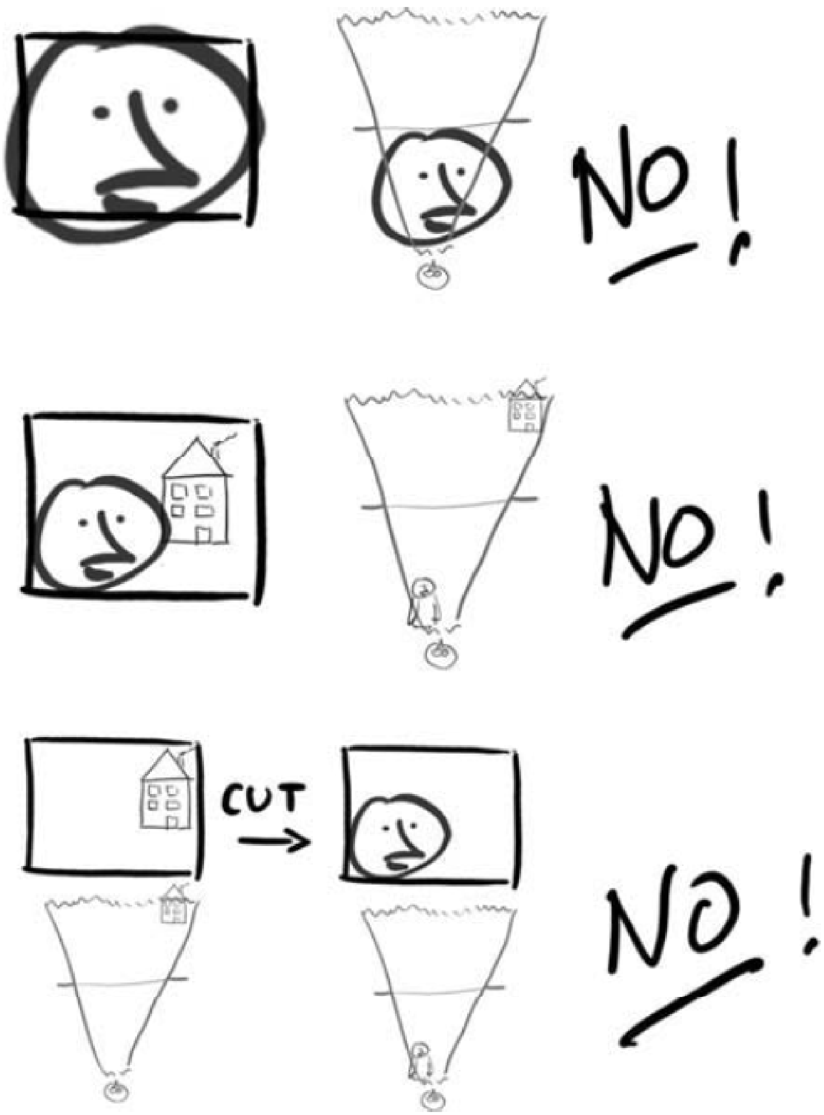
- There is an area around it where vergence and accommodation agree, which is called zone of comfort. This discrepancy could damage the visual acuity before the age of 8.



Principles to avoid fatigue

- Maintain coordination among views
- Have a continuous depth chart
- Place rest area between strong 3D shots
- Use shallow depth of field for excessive depth range
- Respect to stereoscopic window

Some other rules



1. Objects can't cross the edges of the screen. As an example, an extreme close-up with the talent's face reaching all four sides of the frame must be set behind the screen.
2. You can't look at something reaching far inside the theater, in front of a background that is far behind the screen.
3. You can't jump cut, such as from a shot centered inside the theater, to a shot far behind the screen.

Excessive depth range

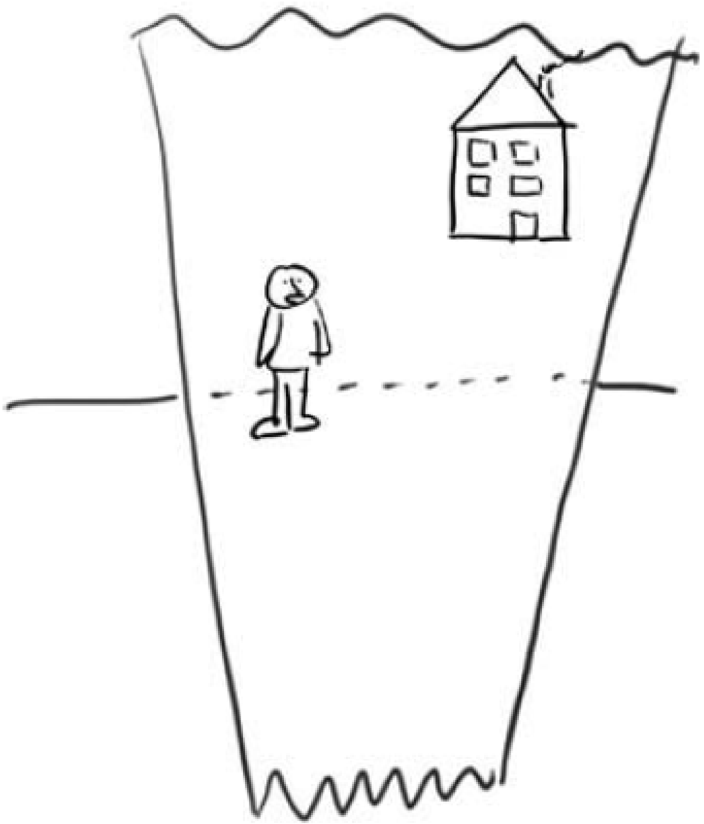


FIGURE 2.17
Background and foreground are both in the comfort zone, and close enough to each other to be fused using the same eye convergence. This is adequate for a character reading a billboard.

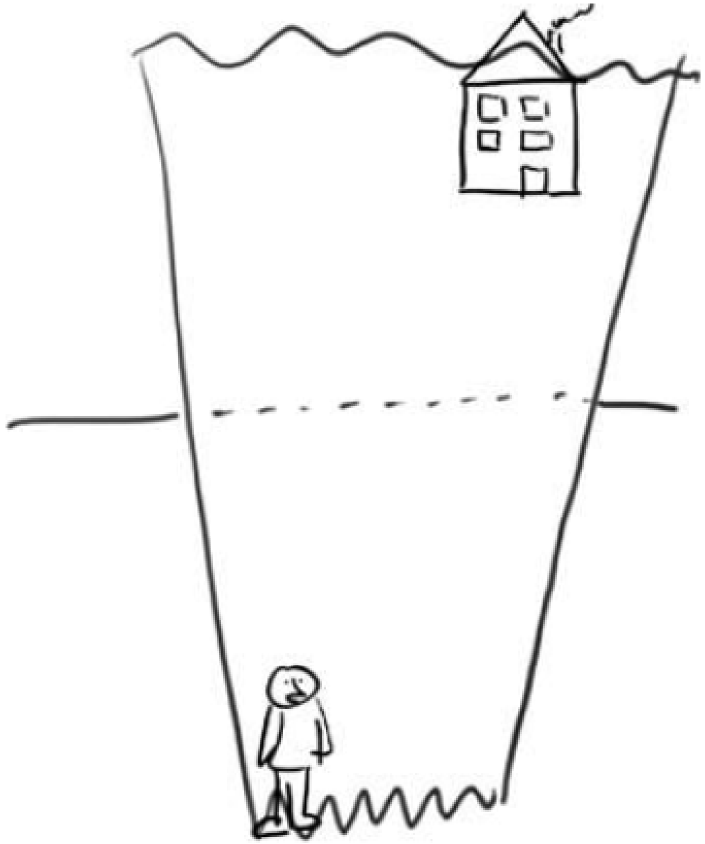
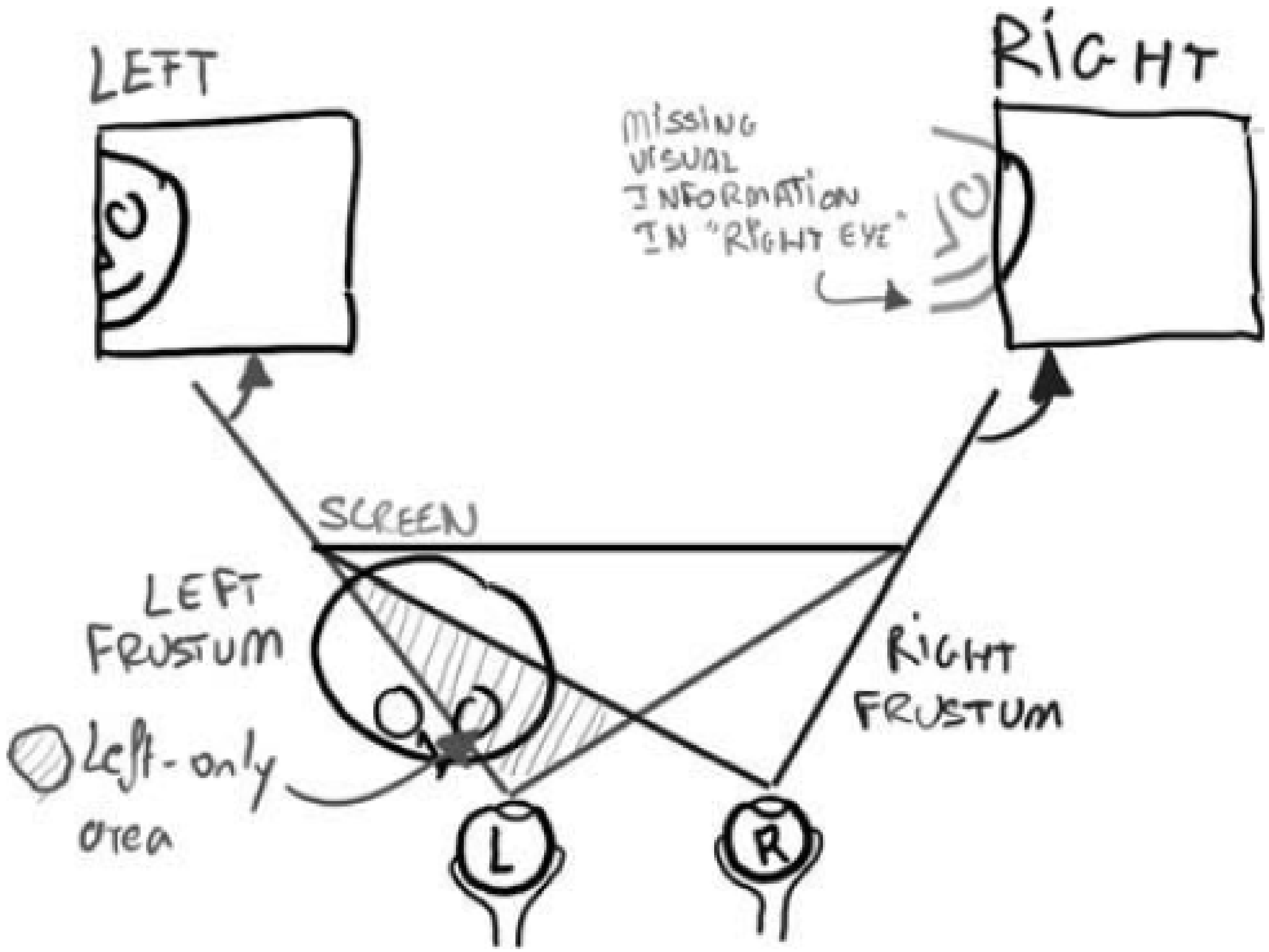


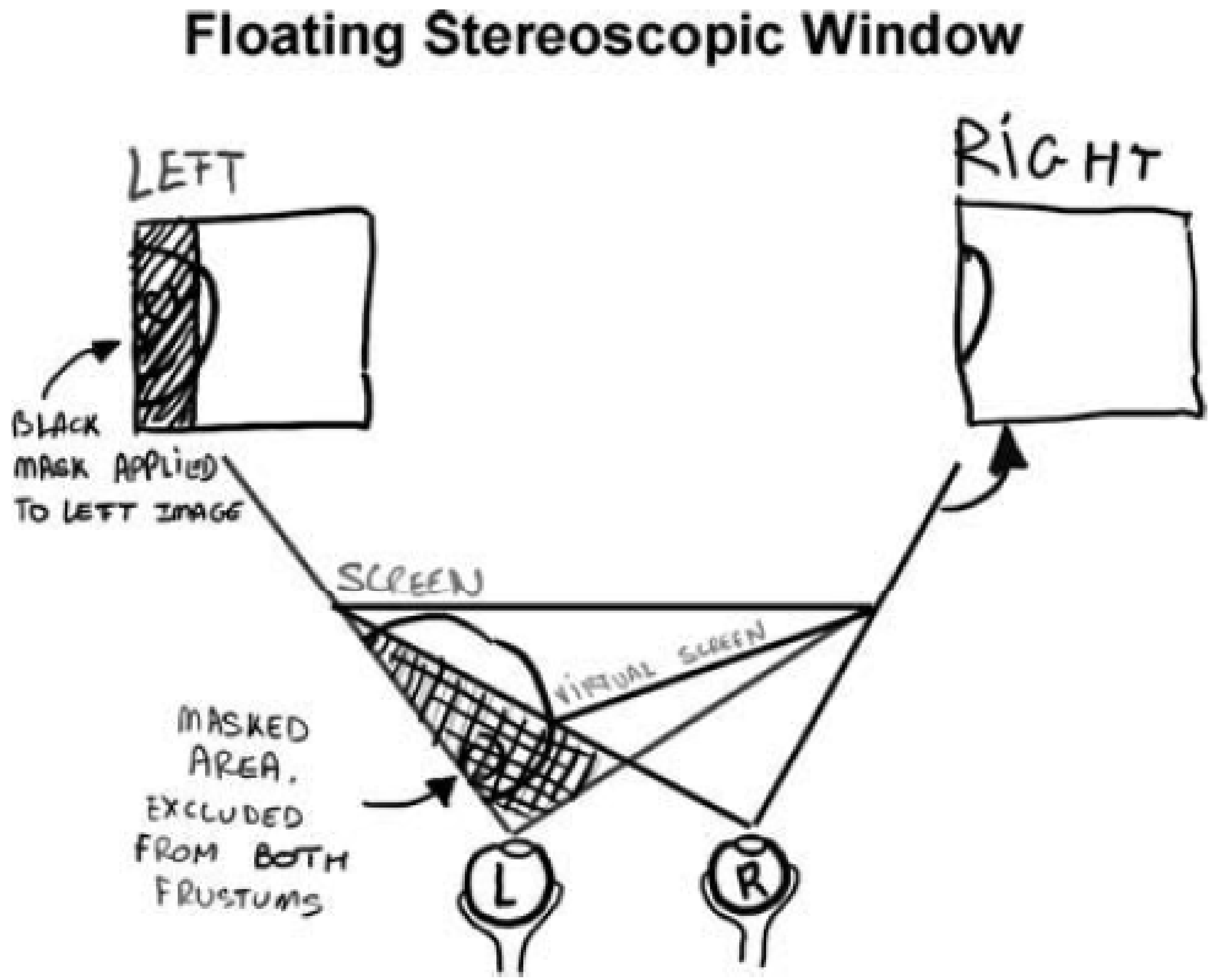
FIGURE 2.18
Background and foreground are both in the comfort zone, but too far away from each other to be fused using the same eye convergence. This is adequate for a character standing in front of a building.

Bending the stereoscopic window

Breaking the stereoscopic window



Floating the stereoscopic window



Without floating

With floating

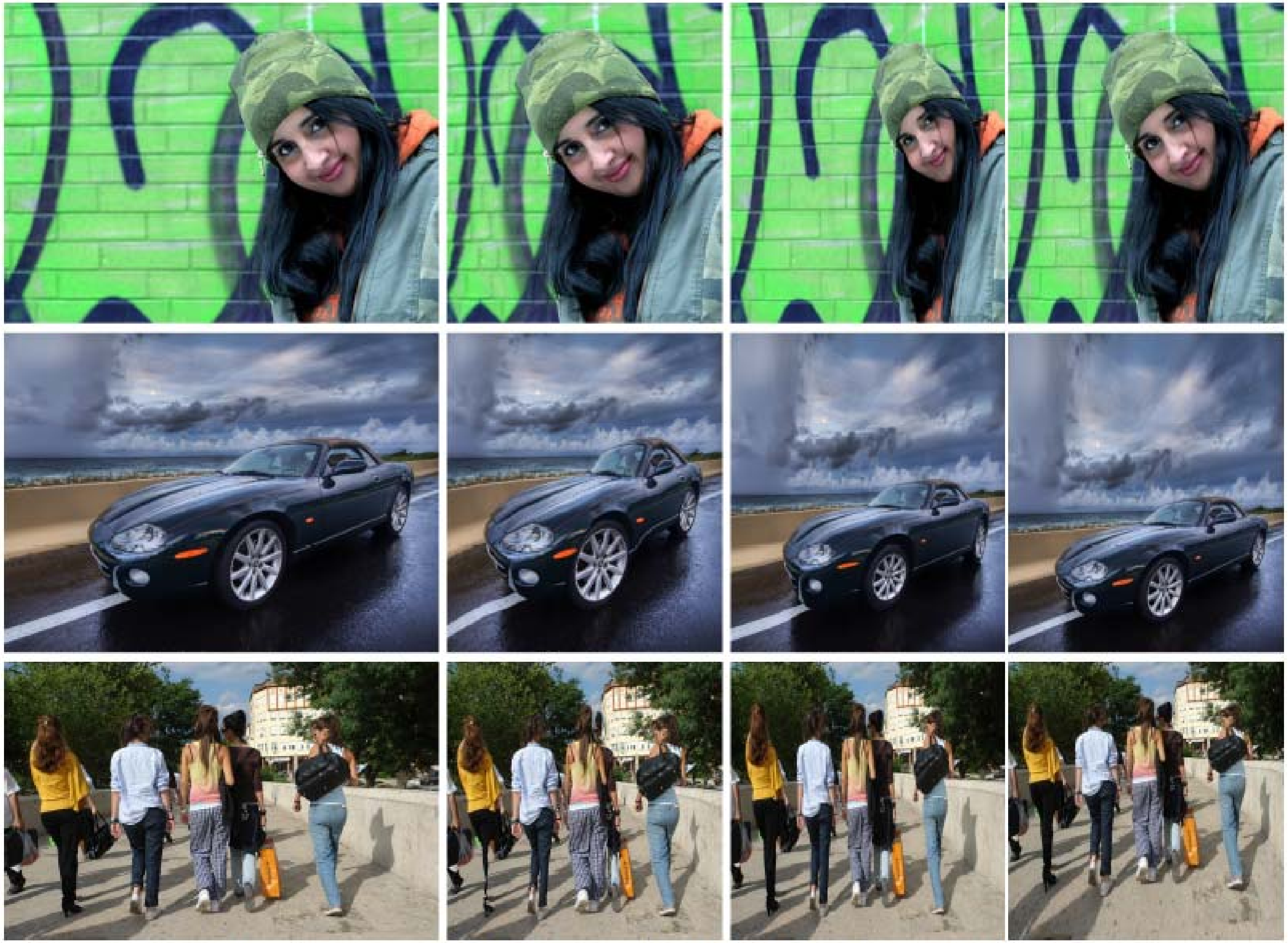
Stereoscopic media postprocessing

Display adaptation

Content-aware display adaptation

- Stereoscopic displays have different resolutions, aspect ratios and comfort zones.
- To display stereoscopic media properly on different displays, we need content-aware stereoscopic image display adaptation methods to perform **image retargeting** and **depth adaptation** simultaneously.

2D media retargeting

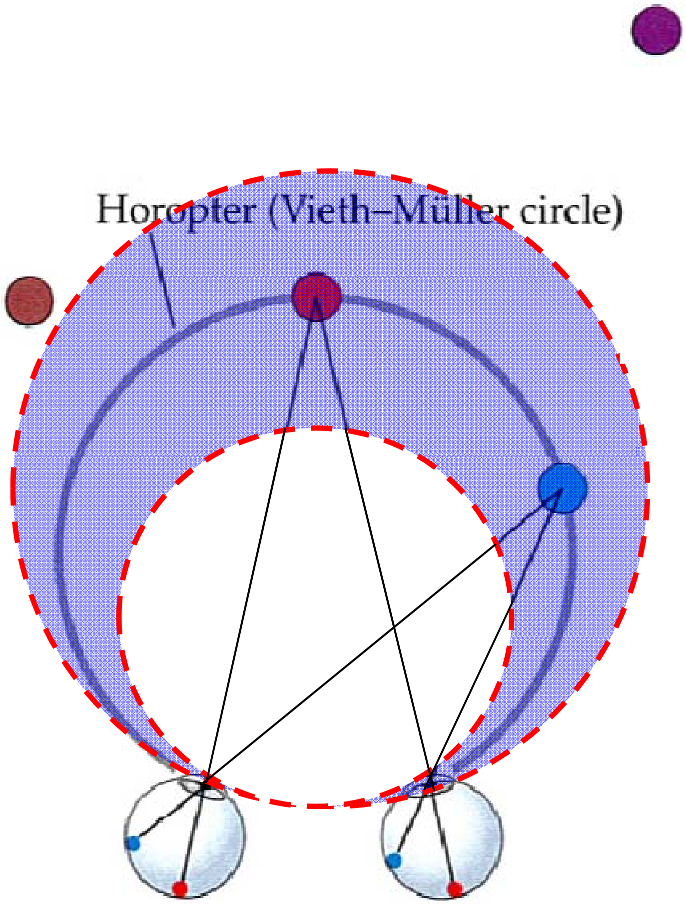

original image | direct forward SC | indirect forward SC | our result

[image resizing video](#)

[video resizing video](#)

Depth adaptation

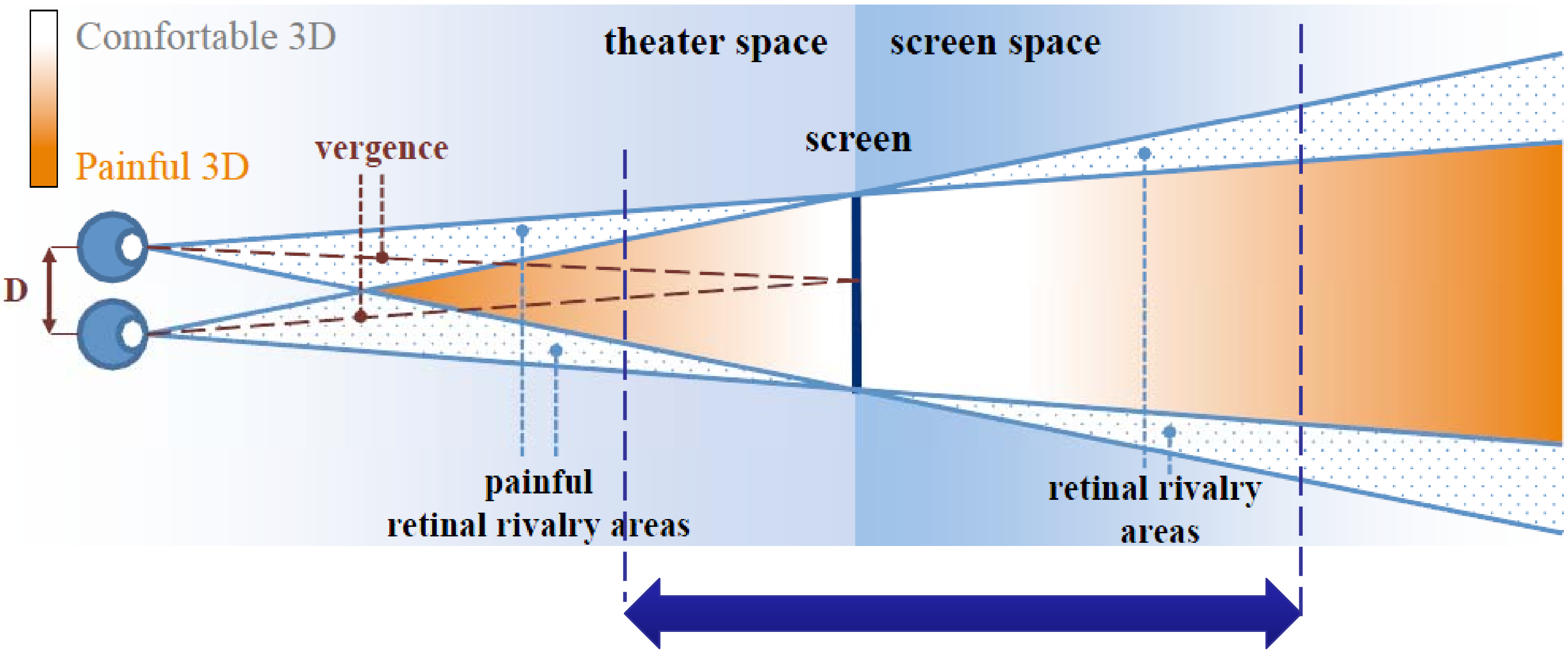
- Adapt depths to the **comfort zone** to avoid visual discomfort such as blur and double vision



Stereoscopic comfort zone

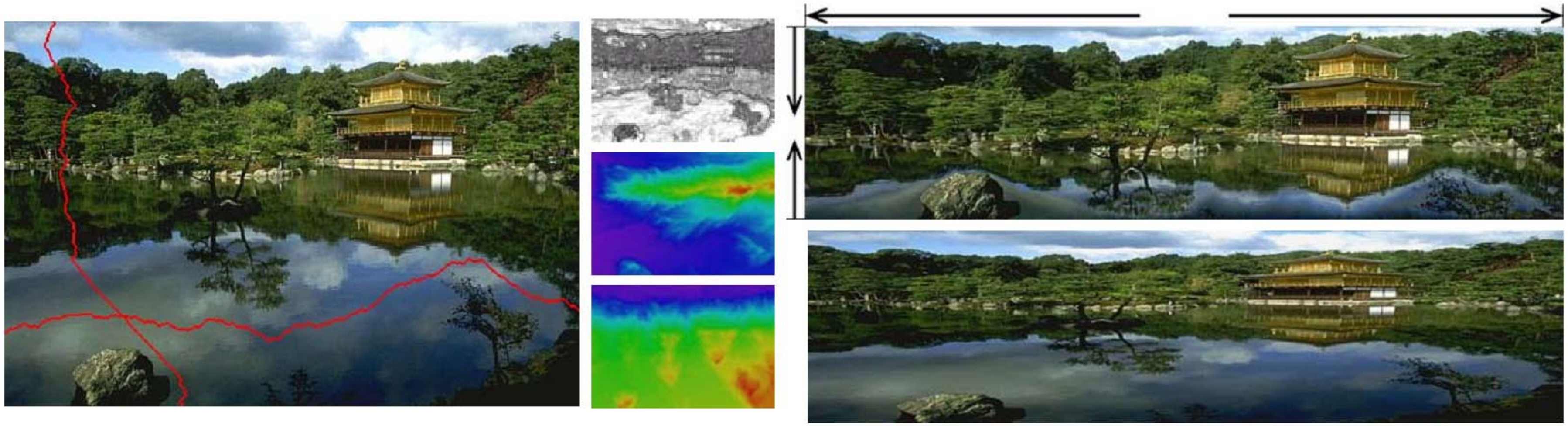
- Vergence (vertical rotation of both eyes in opposite directions to maintain binocular vision)
- Accommodation (change of focus)
- Since accommodation and vergence are reflexively coupled mechanisms, their artificial decoupling when viewing stereoscopic displays has often been theorized as a significant factor underlying the occurrence of visual discomfort
- The ranges of accommodation and vergence that can be achieved without any excessive errors in either direction are referred to as *the zone of clear single binocular vision*

Stereoscopic comfort zone



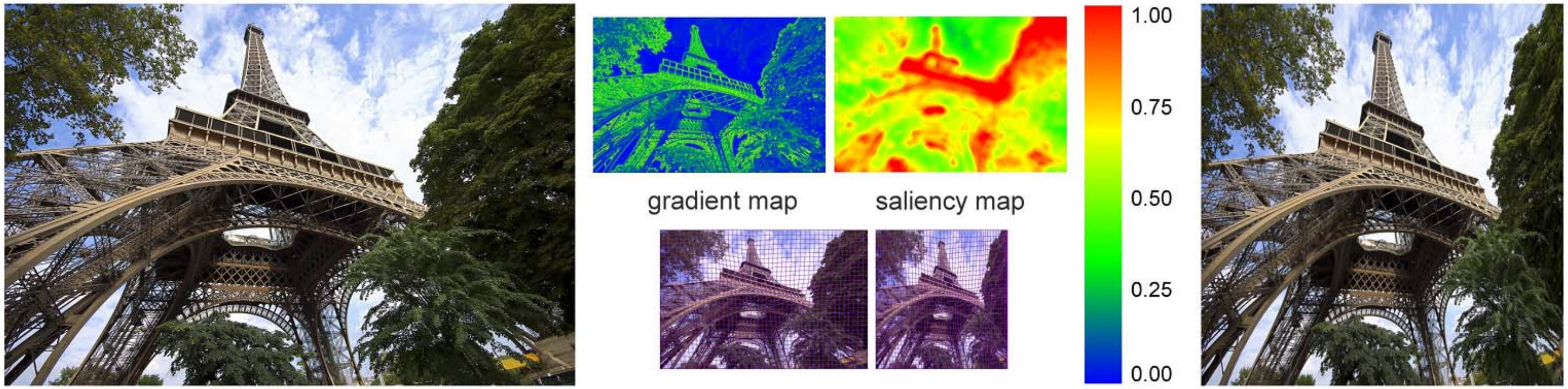
Previous work (2D image resizing)

- Seam Carving for Content-Aware Image Resizing
  [Avidan *et al*., SIGGRAPH07]

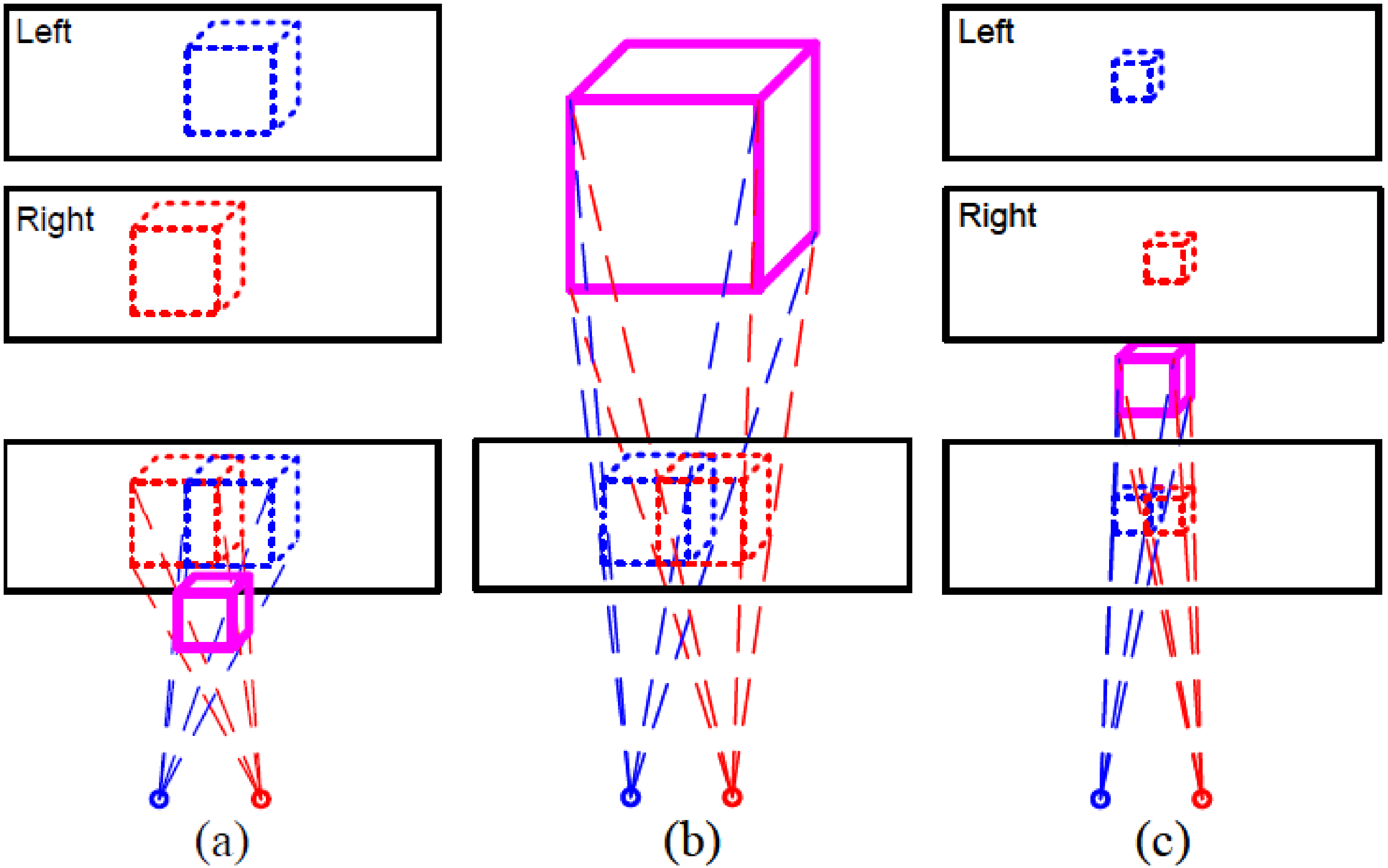


Previous work (2D image resizing)

- Optimized scale-and-stretch (OSS)
  [Wang *et al*., SIGGRAPH ASIA08]

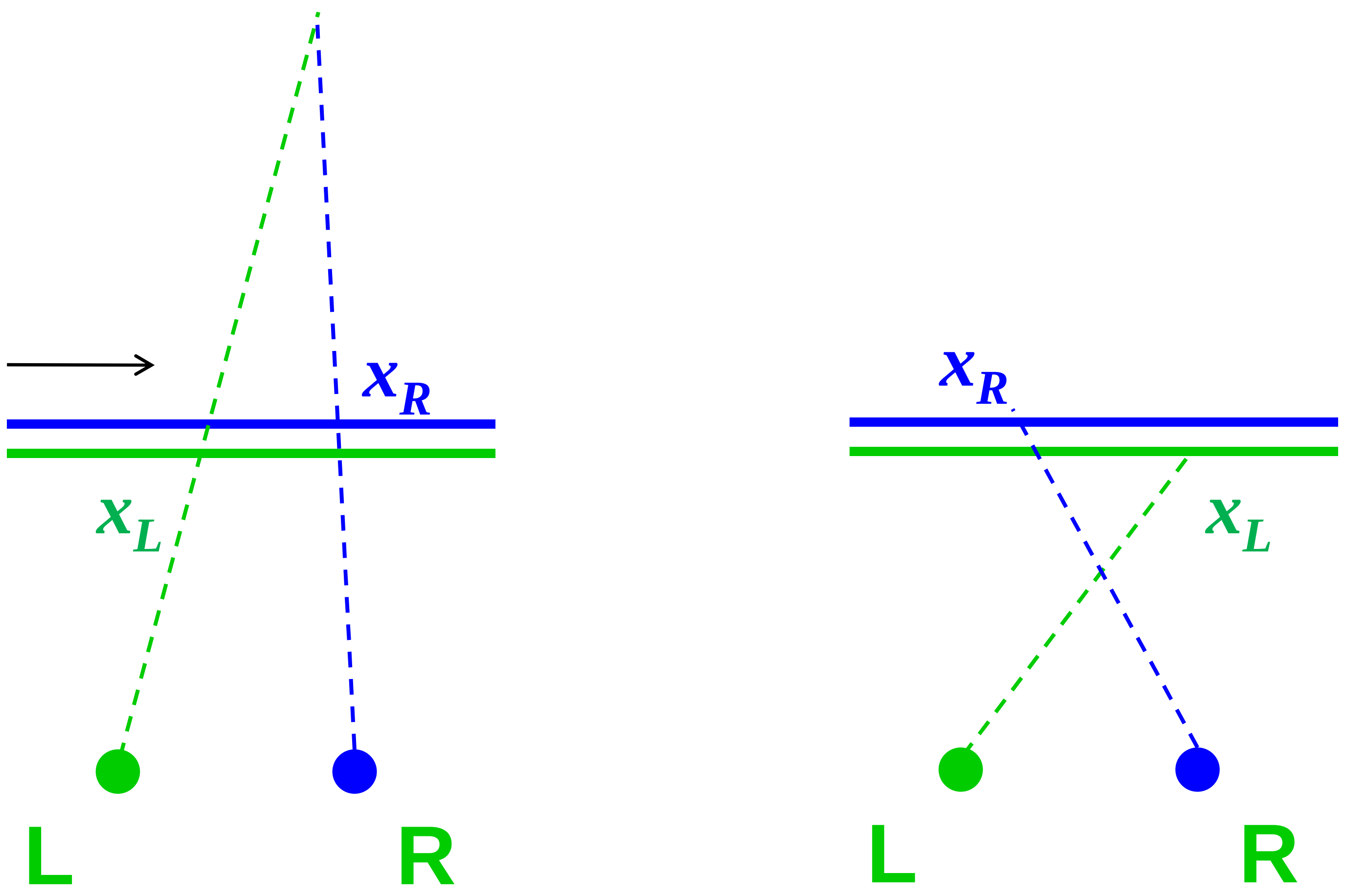


Previous work (linear shift)

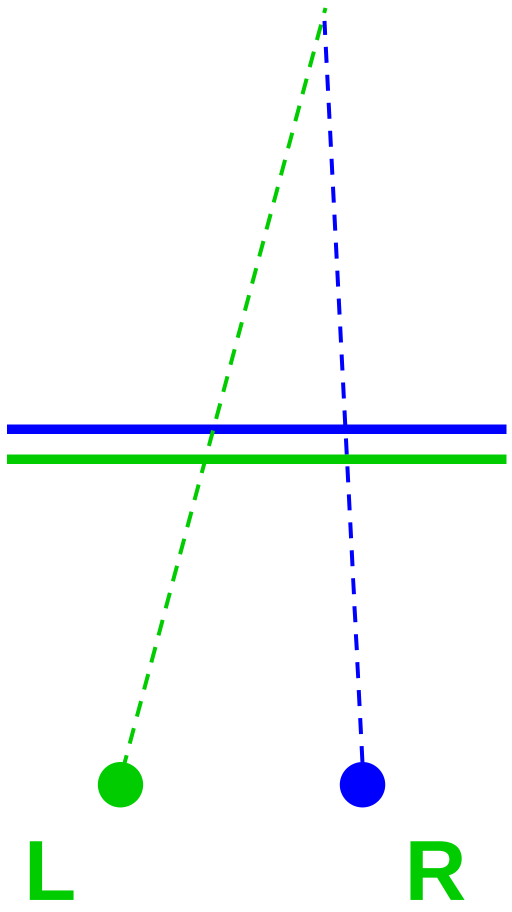


Content-aware Display Adaptation and Interactive Editing for Stereoscopic Images

Mapping between disparities and depths

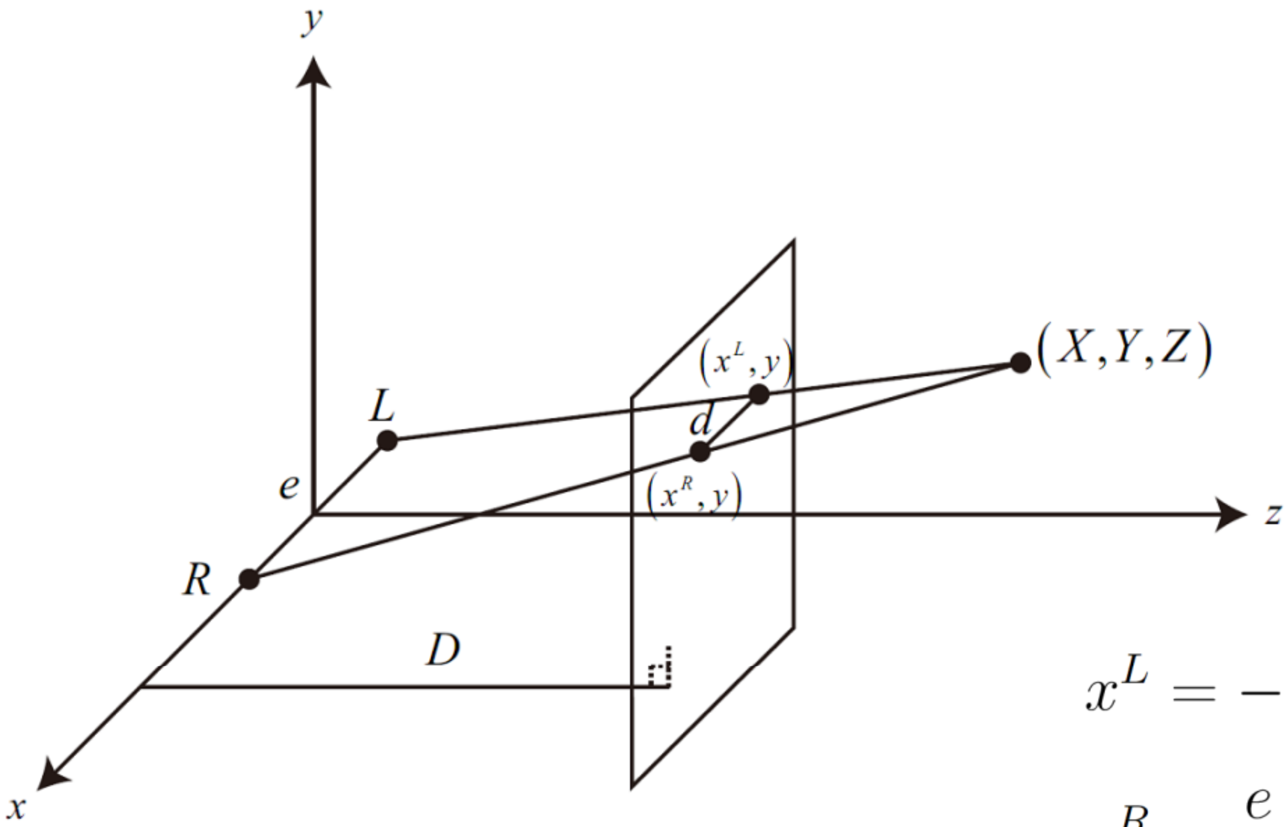


Mapping between disparities and depths



$$Z = \frac{eD}{e - d}$$

Mapping between disparities and depths

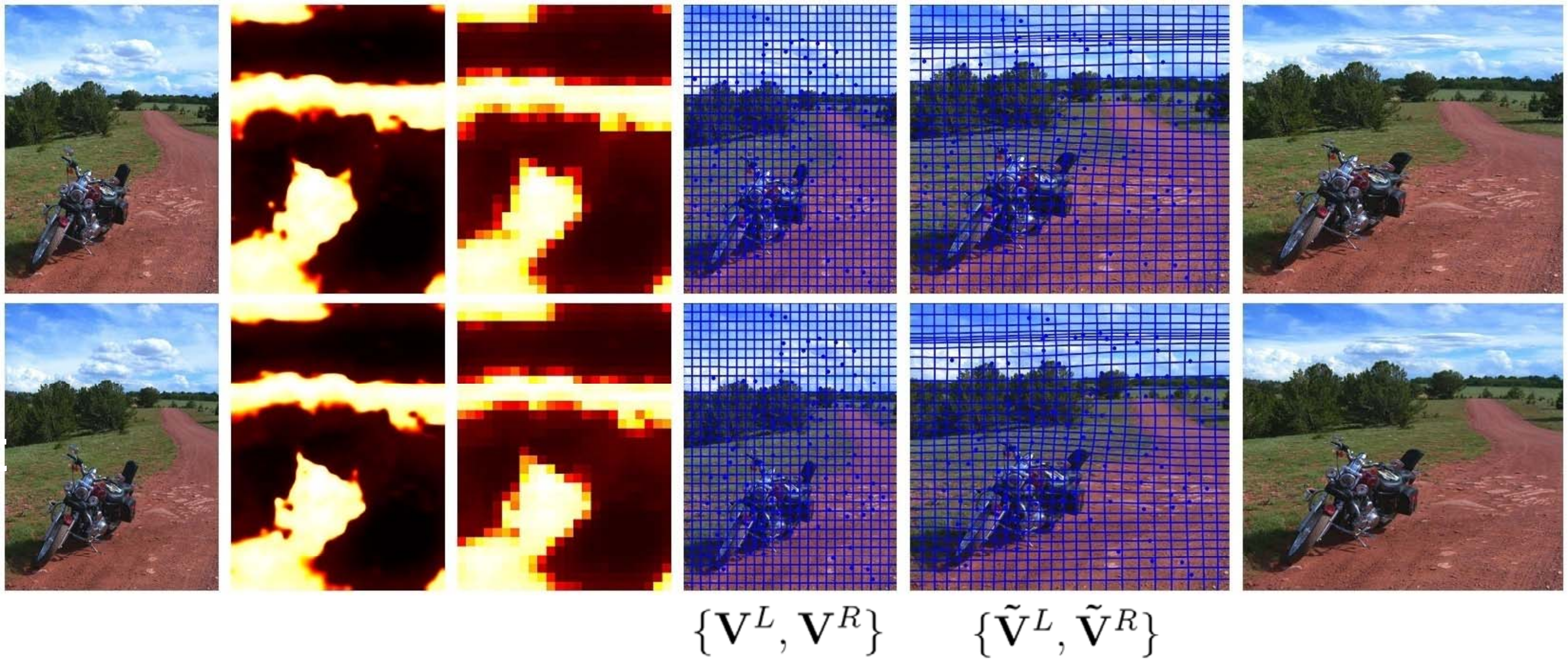


$$x^L = -\frac{e}{2} + \left(X + \frac{e}{2}\right)\frac{D}{Z}$$

$$x^R = \frac{e}{2} + \left(X - \frac{e}{2}\right)\frac{D}{Z}$$

$$(X, Y, Z)^T = \frac{e}{e-d}\left(\frac{x^L + x^R}{2}, y, D\right)^T \qquad y = Y\frac{D}{Z}.$$

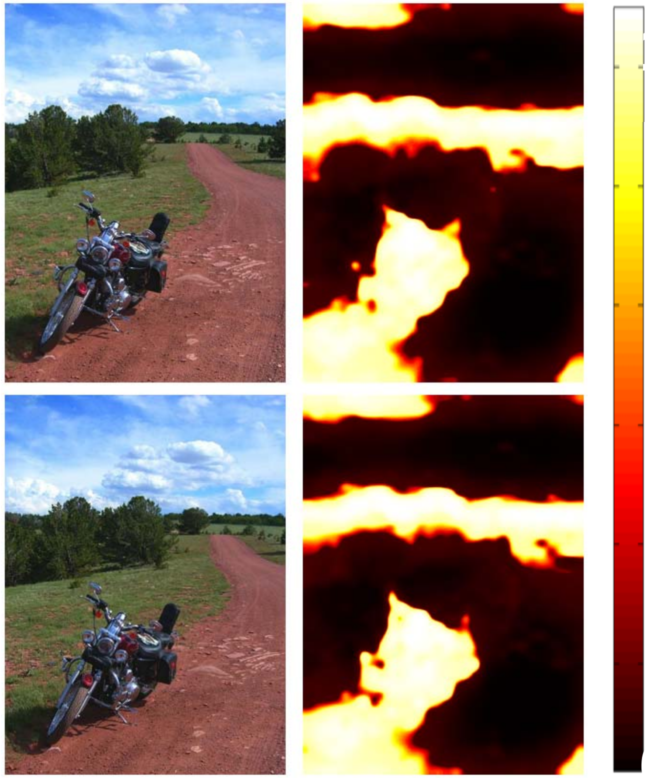
Overview



- Minimize $\Psi(\tilde{\mathbf{V}}^L, \tilde{\mathbf{V}}^R)$

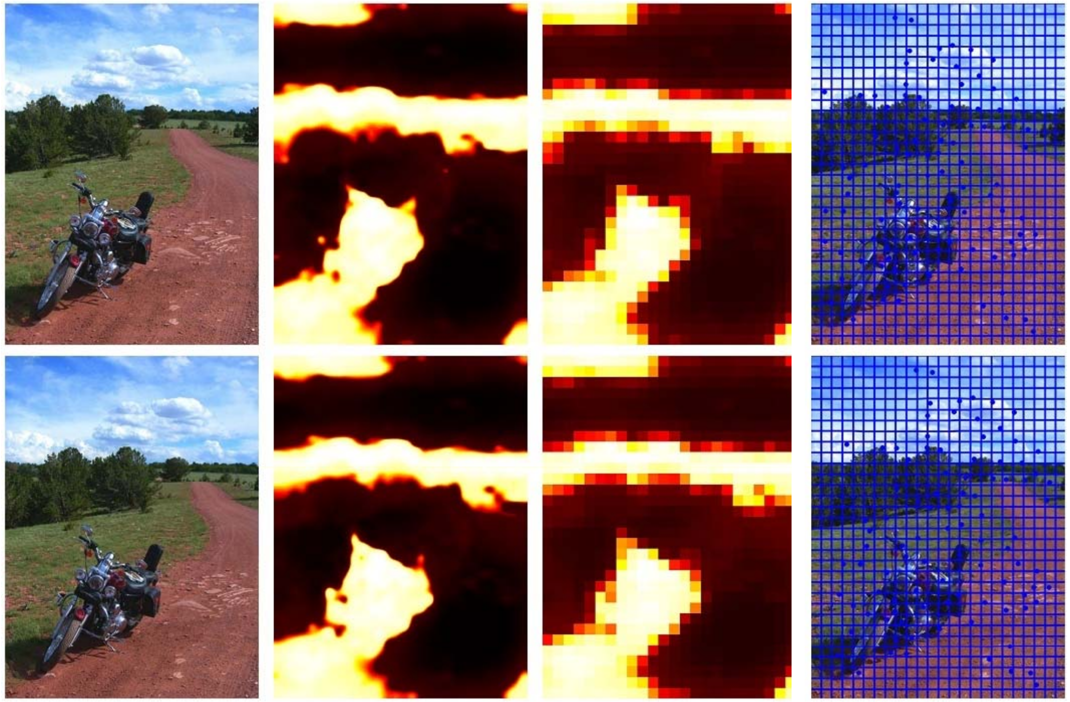
Saliency detection

- Graph-based visual saliency algorithm [Jonathan *et al*., NIPS06]



Mesh representation

- An image is represented as a rectangular mesh



Quad importance

- Average of saliency values of all pixels in q

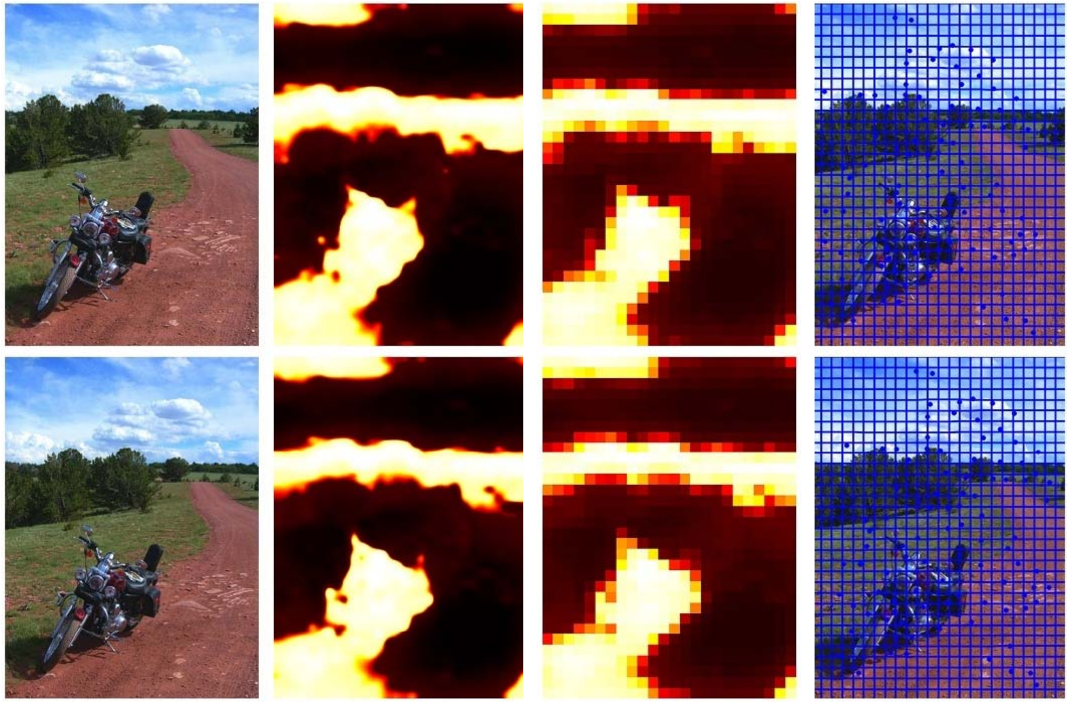
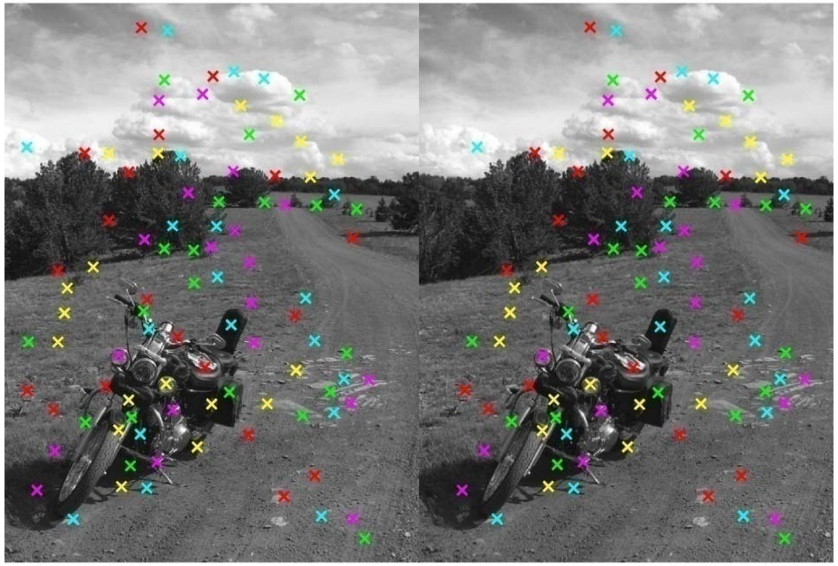


Image correspondence

- Build the stereoscopic constraints
- The state-of-the-art stereo methods are still far from perfection
- We only use **sparse features pairs**
  - Reliable
  - "Sparse correspondences + image warping" are often enough to fool human brain

Feature correspondence

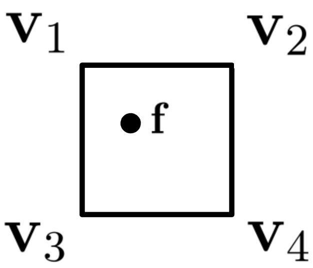
- Feature extraction
  - SIFT feature
- Feature matching
- Verification
  - Estimate fundamental matrix using RANSAC
- Non-maximal suppression



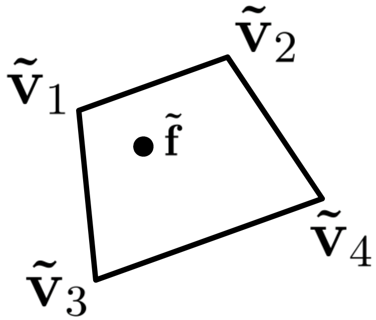
$$\mathbf{F} = \{(\mathbf{f}_i^L, \mathbf{f}_i^R)\}$$

Feature correspondence

- $\tilde{\mathbf{f}}$ is expressed as a linear combination of $\tilde{\mathbf{v}}_i$



$\mathbf{f} = 0.42\mathbf{v}_1 + 0.18\mathbf{v}_2 + 0.12\mathbf{v}_3 + 0.28\mathbf{v}_4$



$\tilde{\mathbf{f}} = 0.42\tilde{\mathbf{v}}_1 + 0.18\tilde{\mathbf{v}}_2 + 0.12\tilde{\mathbf{v}}_3 + 0.28\tilde{\mathbf{v}}_4$

Energy minimization

- Energy function

$$\Psi = \underline{\Psi_d + \lambda_b \Psi_b} + \lambda_a \Psi_a + \lambda_c \Psi_c$$

Content preservation

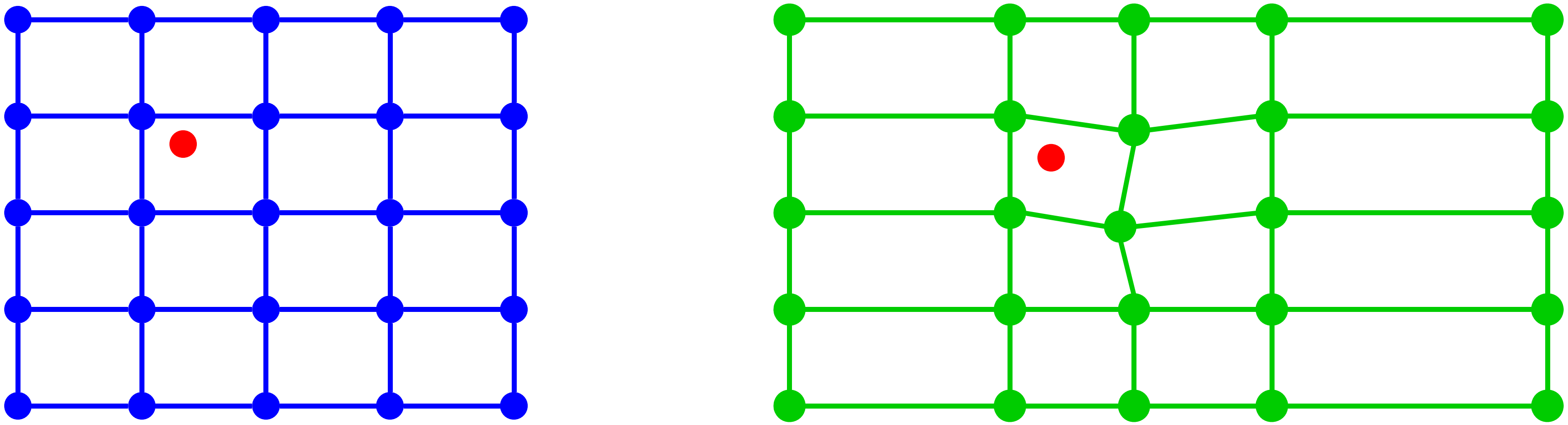
Ψ_d Distortion energy

Ψ_b Line bending energy

Ψ_a Alignment energy

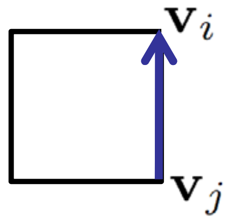
Ψ_c Consistent disparity energy

Energy minimization



Distortion energy

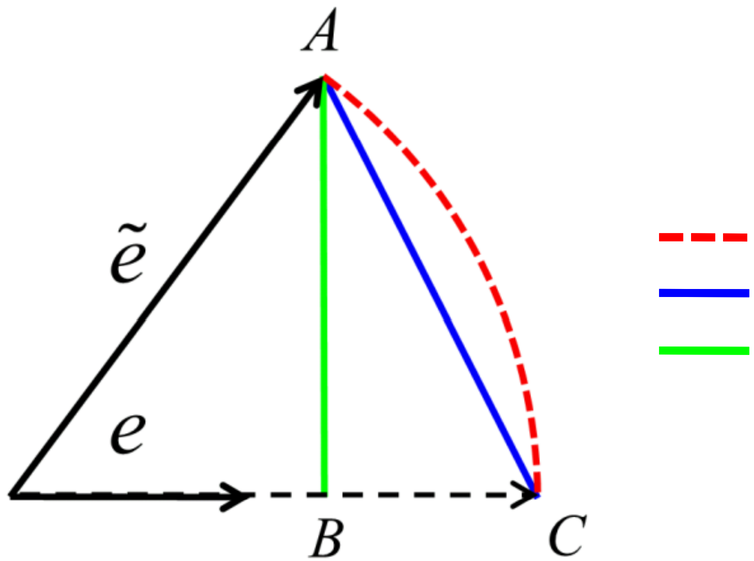
$$\Psi_q(q) = \sum_{(i,j)\in\mathbf{E}(q)} \| (\tilde{\mathbf{v}}_i - \tilde{\mathbf{v}}_j) - s_q (\mathbf{v}_i - \mathbf{v}_j) \|^2$$



- The optimal s_q is completely defined by $\mathbf{v}_i$ and $\tilde{\mathbf{v}}_i$

Line bending energy

$$\Delta(\tilde{\mathbf{e}}) = \|s\mathbf{e} - \tilde{\mathbf{e}}\|^2$$



Energy minimization

$$\Psi = \Psi_d + \lambda_b \Psi_b + \underline{\lambda_a \Psi_a + \lambda_c \Psi_c}$$

Stereoscopic constraints

Ψ_d Distortion energy

Ψ_b Line bending energy

Ψ_a Alignment energy

Ψ_c Consistent disparity energy

Alignment energy

- Maintain purely horizontal parallax (avoid vertical parallax)

$$\Psi_a = \sum_{i=1}^{n} \left(\tilde{\mathbf{f}}_i^L[y] - \tilde{\mathbf{f}}_i^R[y] \right)^2$$

Consistent disparity energy

- Maintain the relative shapes and depths

$$\Psi_c = \sum_{i=1}^{n} \left((s d_i + t) - \tilde{d}_i \right)^2 \quad \text{where } d_i = \mathbf{f}_i^R[x] - \mathbf{f}_i^L[x] \text{ and } \tilde{d}_i = \tilde{\mathbf{f}}_i^R[x] - \tilde{\mathbf{f}}_i^L[x].$$

- Keep the absolute shapes and depths

$$\Psi_c = \sum_{i=1}^{n} \left(d_i - \tilde{d}_i \right)^2$$

Energy minimization

- Energy function

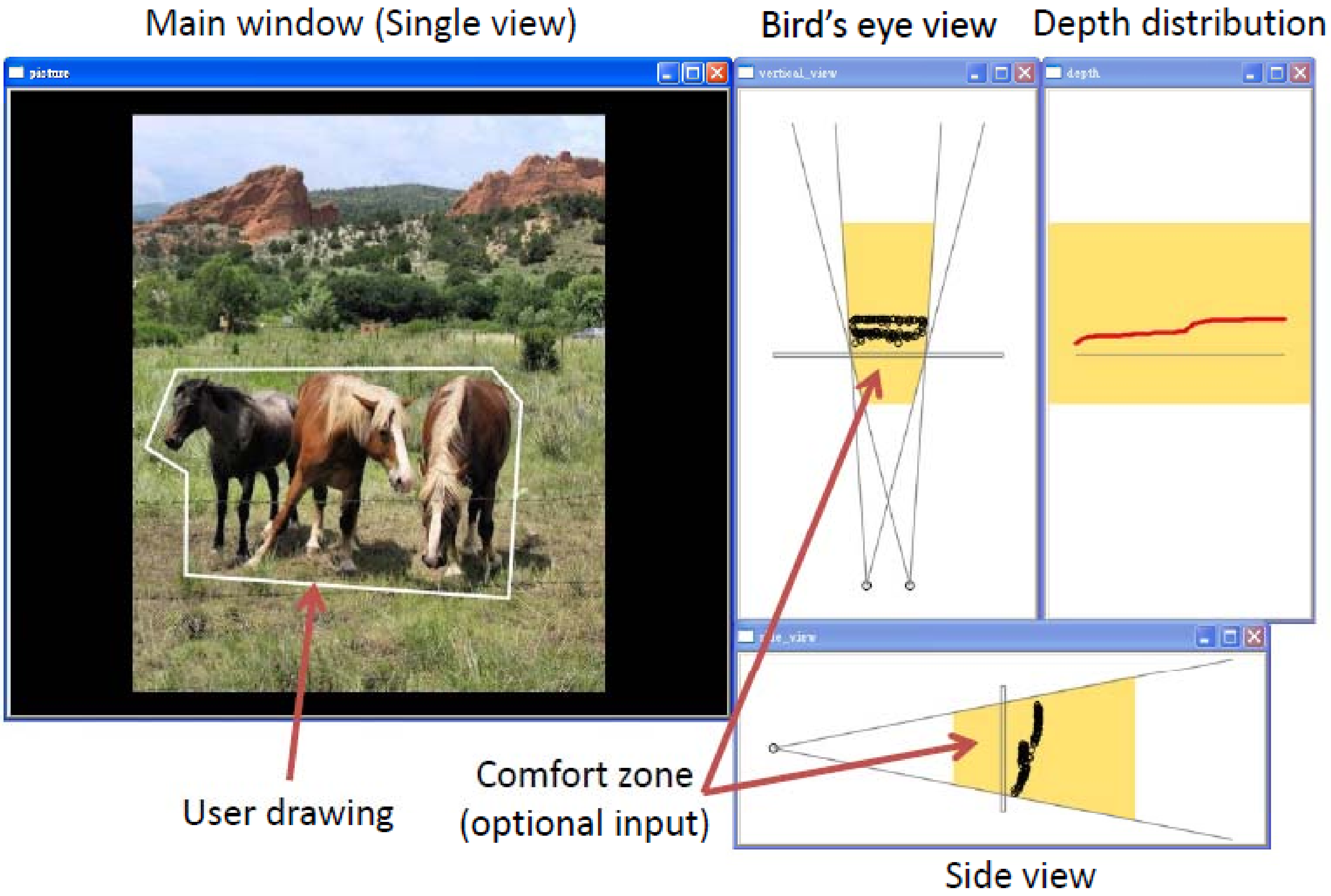
$$\Psi = \Psi_d + \lambda_b \Psi_b + \lambda_a \Psi_a + \lambda_c \Psi_c$$

- Linear least squares problem → closed form solution

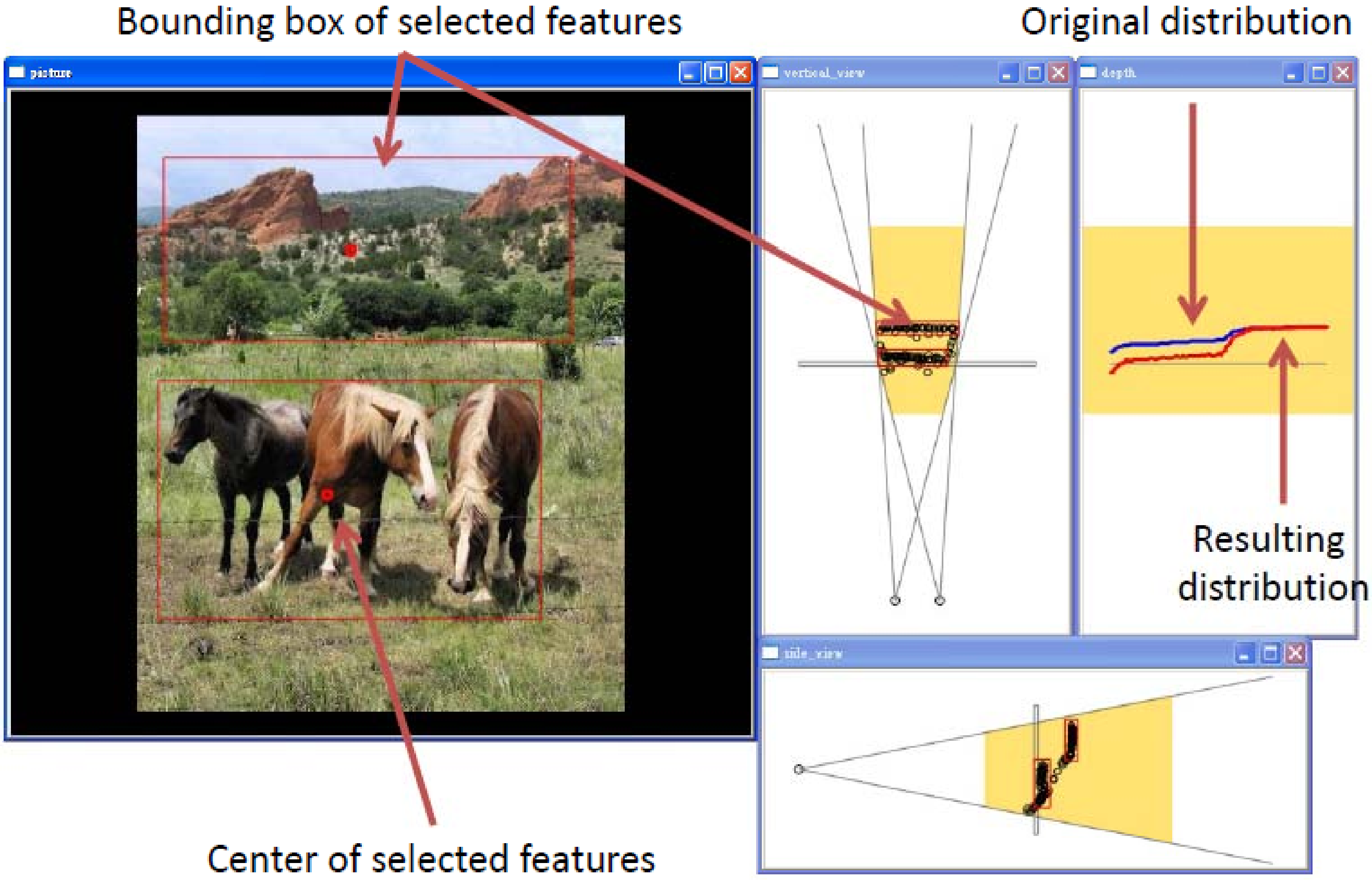
User editing

- User specifies depths (Z-axis)
- User specifies 3D position (XYZ-axis)

User editing



User editing

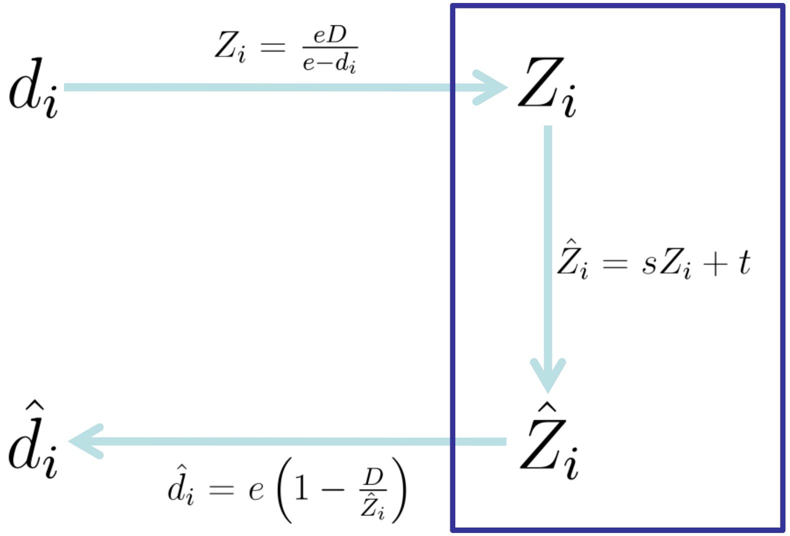


User editing

- User specifies depths (Z-axis)

$$\Psi_c = \sum_{i=1}^{n} \left(\tilde{d}_i - \underline{\hat{d}_i} \right)^2$$

Target disparity



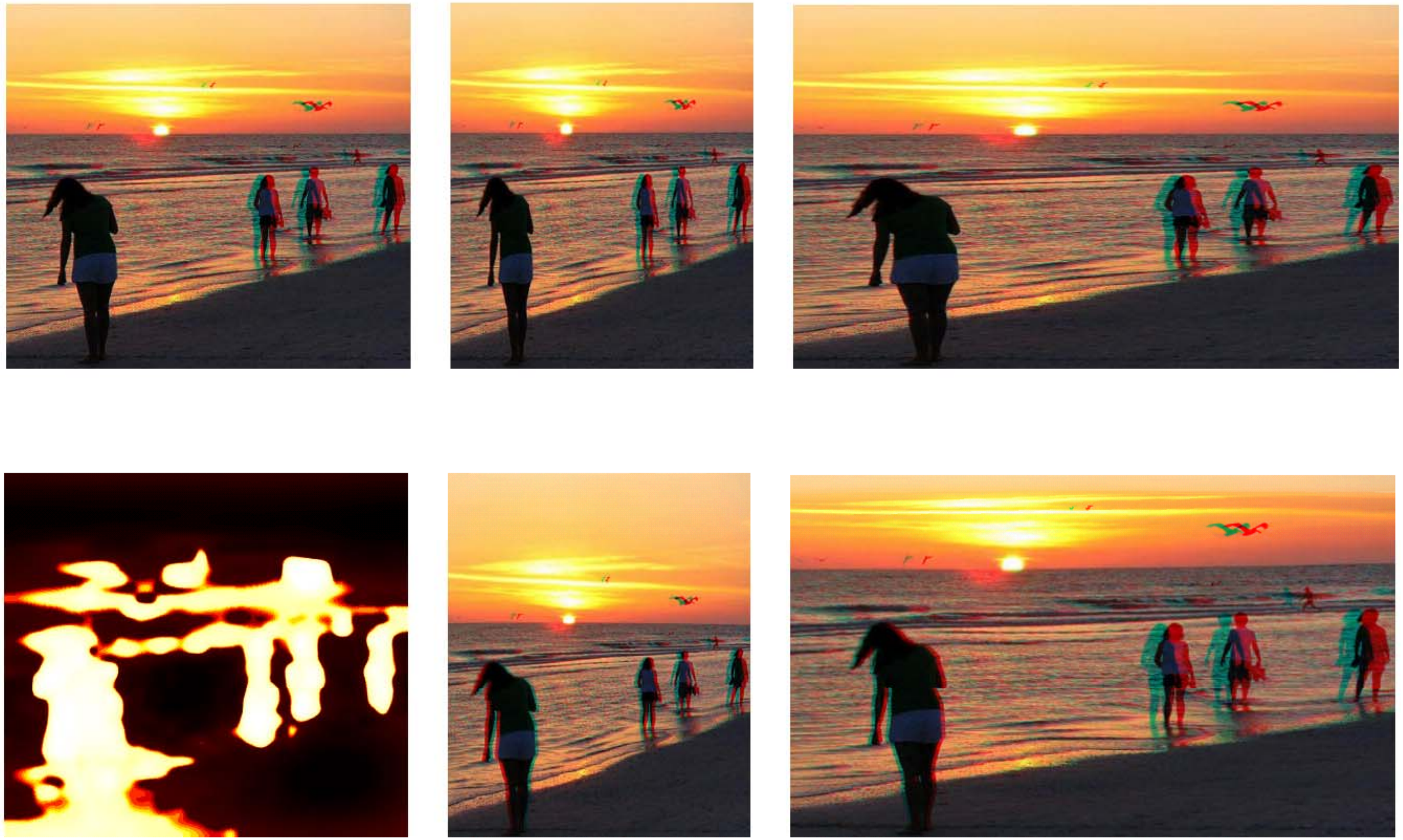
User editing

- User specifies 3D position (XYZ-axis)

$$\Psi_c = \sum_{i \in \hat{\mathbf{F}}} \left(\|\tilde{\mathbf{f}}_i^L - \underline{\hat{\mathbf{f}}_i^L}\|^2 + \|\tilde{\mathbf{f}}_i^R - \underline{\hat{\mathbf{f}}_i^R}\|^2 \right) + \lambda \sum_{i \in \mathbf{F} - \hat{\mathbf{F}}} \left((sd_i + t) - \tilde{d}_i \right)^2 .$$

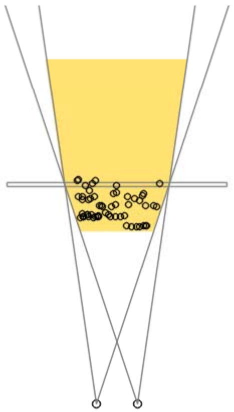
Target 2D position

Results

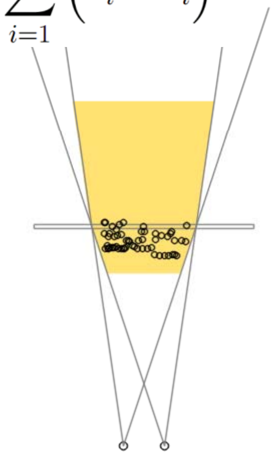


Results

$$\Psi_c = \sum_{i=1}^{n} \left((sd_i + t) - \tilde{d}_i \right)^2$$



$$\Psi_c = \sum_{i=1}^{n} \left(d_i - \tilde{d}_i \right)^2$$

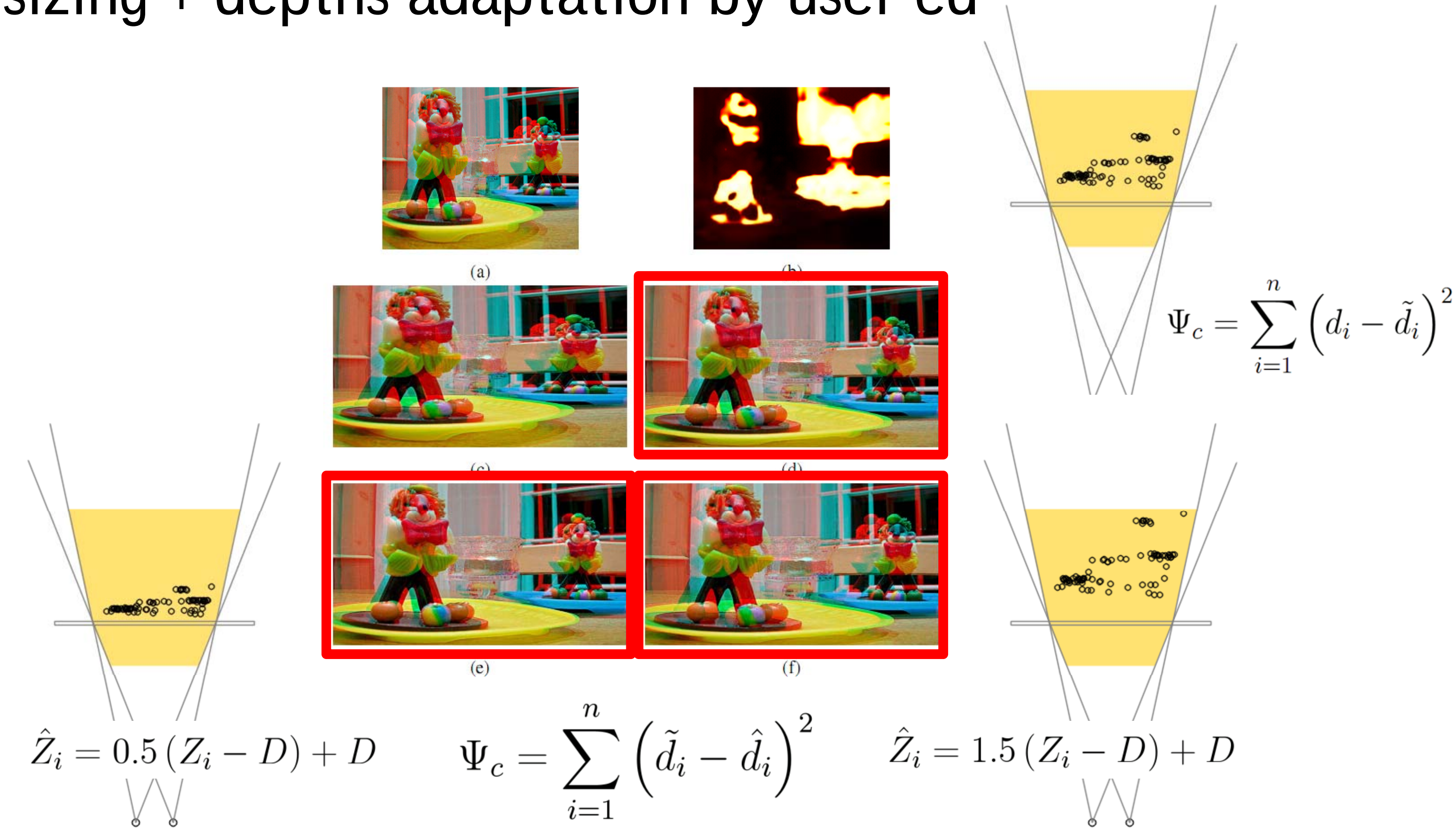


Results

(a) Original (b) Scaling (c) OSS (d) Our method

Results

- Resizing + depths adaptation by user ed

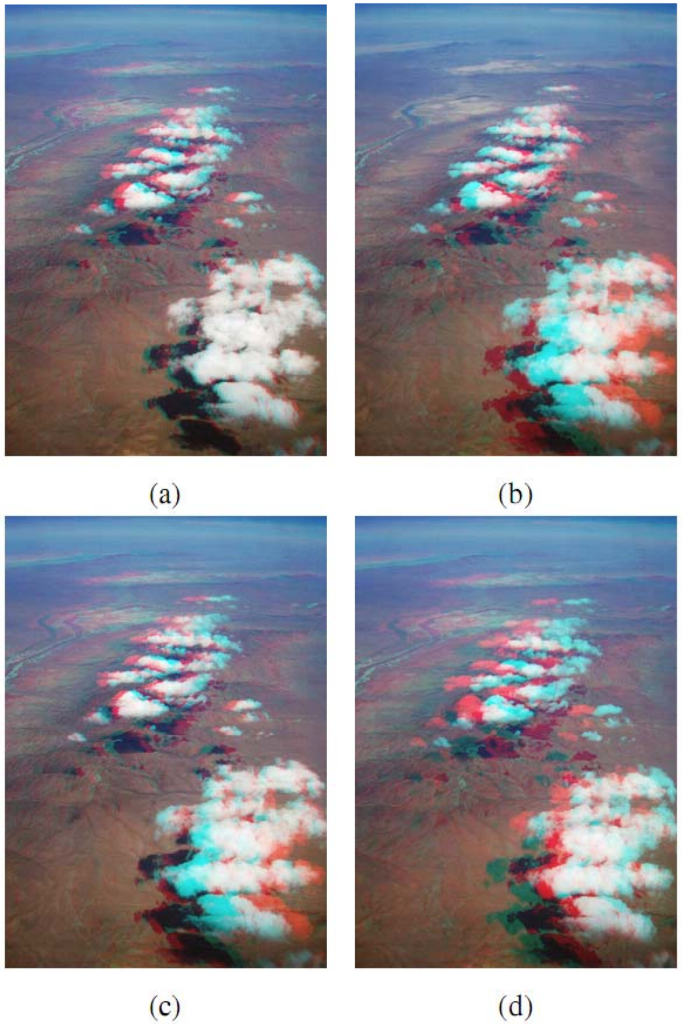


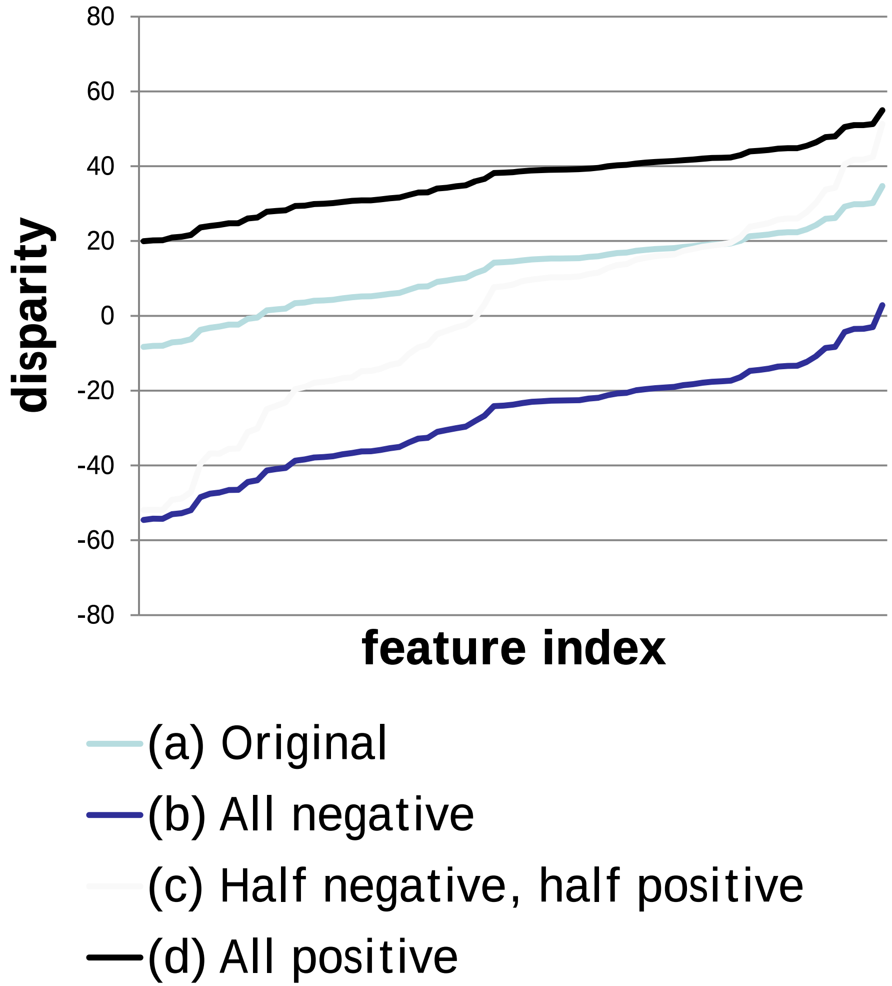
$$\Psi_c = \sum_{i=1}^{n} \left(d_i - \tilde{d}_i\right)^2$$

$$\hat{Z}_i = 0.5\,(Z_i - D) + D \qquad \Psi_c = \sum_{i=1}^{n} \left(\tilde{d}_i - \hat{d}_i\right)^2 \qquad \hat{Z}_i = 1.5\,(Z_i - D) + D$$

Results

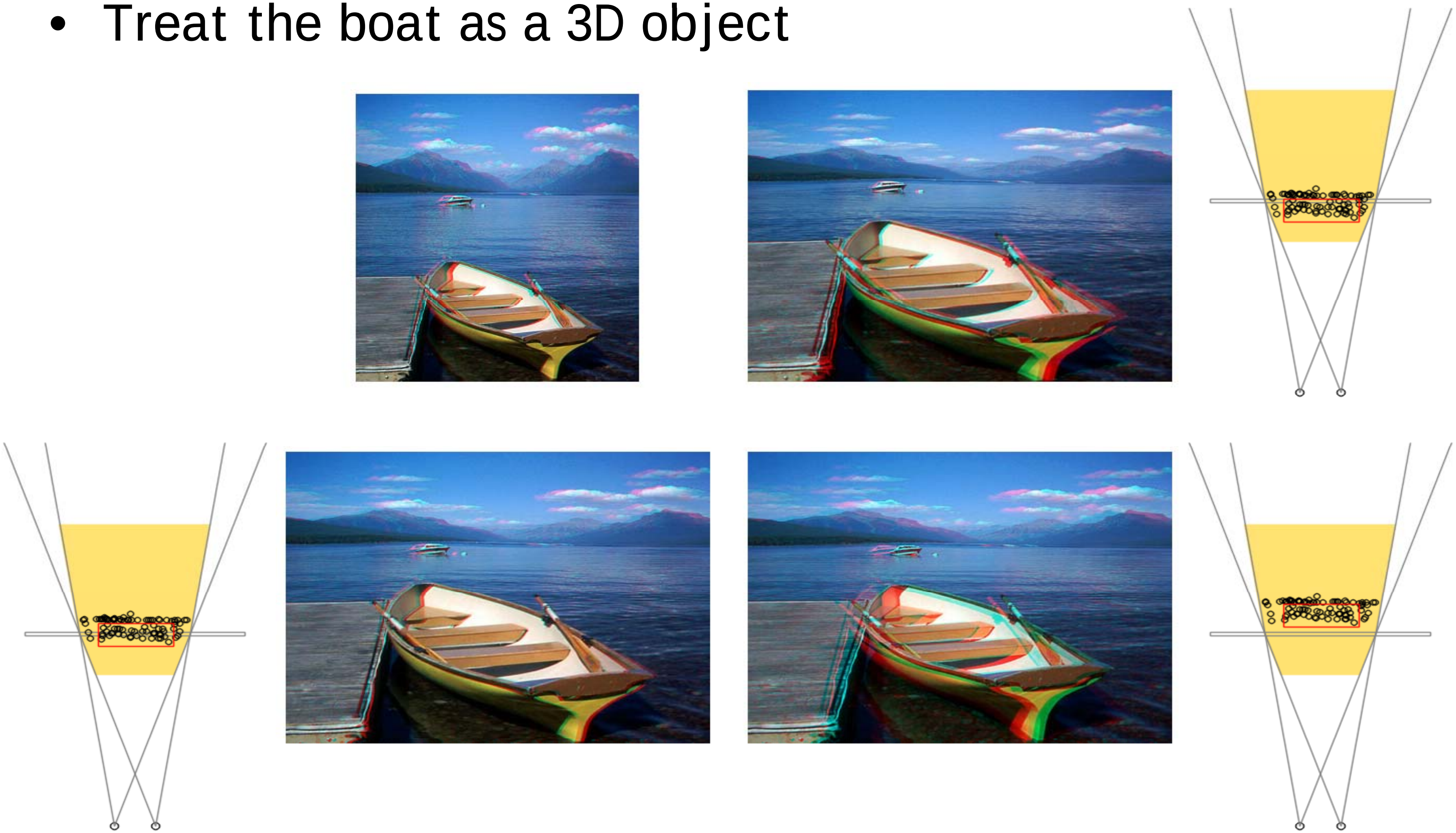
- Depth adaptation by user editing





Results

- Depth adaptation by user editing
- Treat the boat as a 3D object

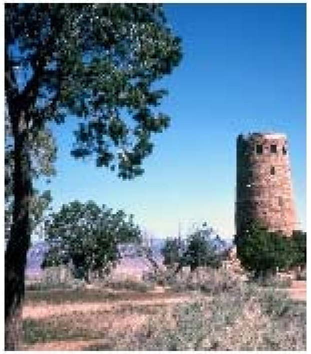


User study

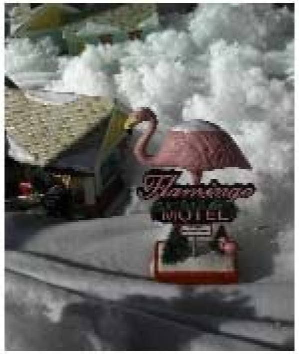
- 24 subjects
- Image resizing
- Depth adaptation

User study - part 1

- Image resizing
  - 1.5x width
  - Comparison with OSS and our method
  - Q: *which viewing is more clear and comfortable?*



(1) 476×549

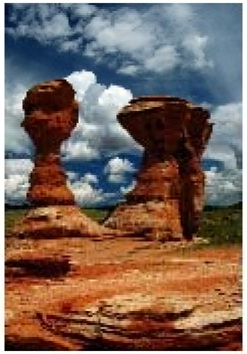


(2) 456×547

(3) 454×758

(4) 574×473

(5) 472×649



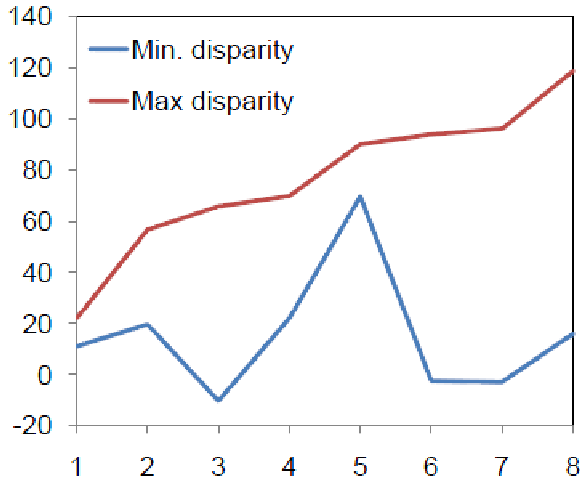
(6) 472×691

(7) 414×760

(8) 472×680

User study - part 1

- Vote rate 90.6% (174/192)
- 92.0% (160/174) prefered our results than OSS's

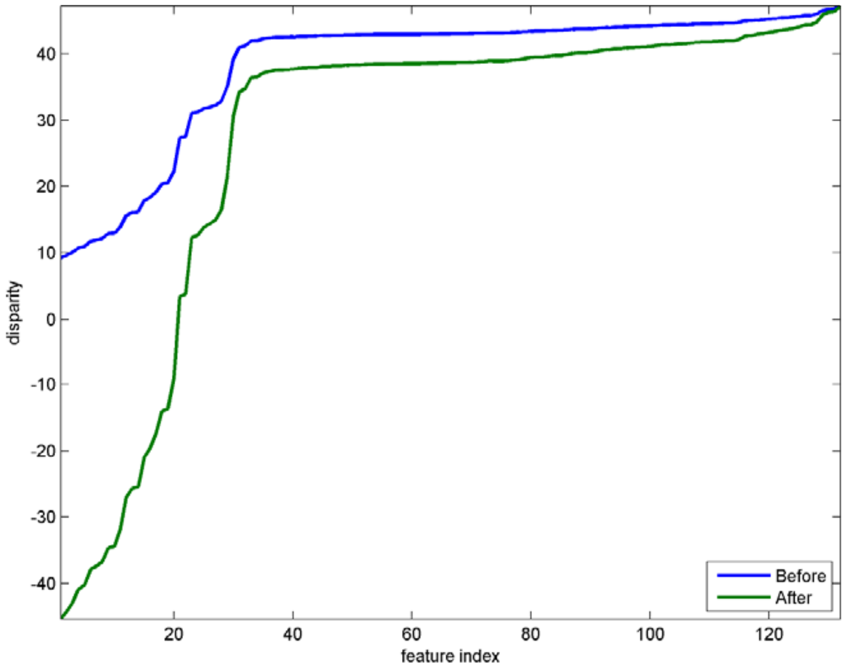


(1) 476×549 (2) 456×547 (3) 454×758 (4) 574×473 (5) 472×649 (6) 472×691 (7) 414×760 (8) 472×680

No.	1	2	3	4	5	6	7	8
Vote rate	96%	71%	100%	79%	92%	92%	100%	96%
Prefer ours	87%	76%	100%	74%	95%	100%	96%	100%

User study - part 2

- Depth adaptation
  - $\hat{Z}_i = 2Z_i - Z_{max}$

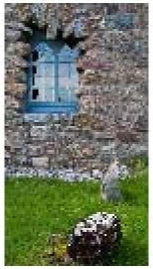


User study - part 2

- Depth adaptation
  - $\hat{Z}_i = 2Z_i - Z_{max}$
  - Q: *which image's foreground area is closer to you?*

(1) 594×578

(2) 470×591



(3) 417×756

(4) 470×612

(5) 470×589

(6) 540×369

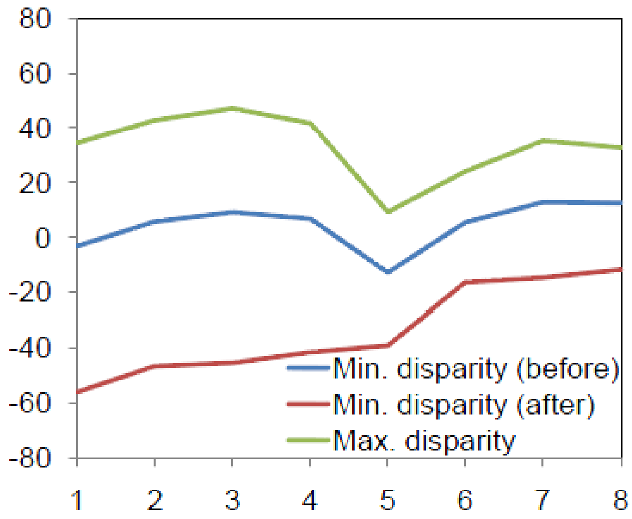
(7) 452×550

(8) 456×754

User study - part 2

DigiVFX

- Vote rate 91.7% (176/192)
- Correct rate 88.6% (156/176)



(1) 594×578 (2) 470×591 (3) 417×756 (4) 470×612 (5) 470×589 (6) 540×369 (7) 452×550 (8) 456×754

No.	1	2	3	4	5	6	7	8
Vote rate	100%	96%	100%	96%	79%	92%	88%	83%
Correct rate	79%	83%	88%	91%	84%	91%	100%	95%

Nonlinear disparity mapping

- video

Stereoscopic copy and paste

- video