The human visual system and distortions in S3D

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EBU TECHNICAL MEDIA TECHNOLOGY & INNOVATION

Where I'm coming from

- Physics undergraduate degree & PhD
- Masters in Neuroscience, Diploma in Psychology
- Vision scientist with >30 papers in international peer-reviewed science journals
- Main research interest = binocular / stereo vision
- www.staff.ncl.ac.uk/j.c.a.read
- Basic science perspective

S3D problems

- Stereoblindness / strabismus / monocular vision
- S3D glasses
- Timing delays between the two eyes
- Low frame rate
- Conflicts with vestibular system
- Vergence/accommodation conflict
- Incorrect geometry and misalignments

Two quick points: 1

- Stereoblindness / strabismus / monocular vision
  - Not actually a problem; simply no benefit
  - Like colourblindness

Two quick points: 2

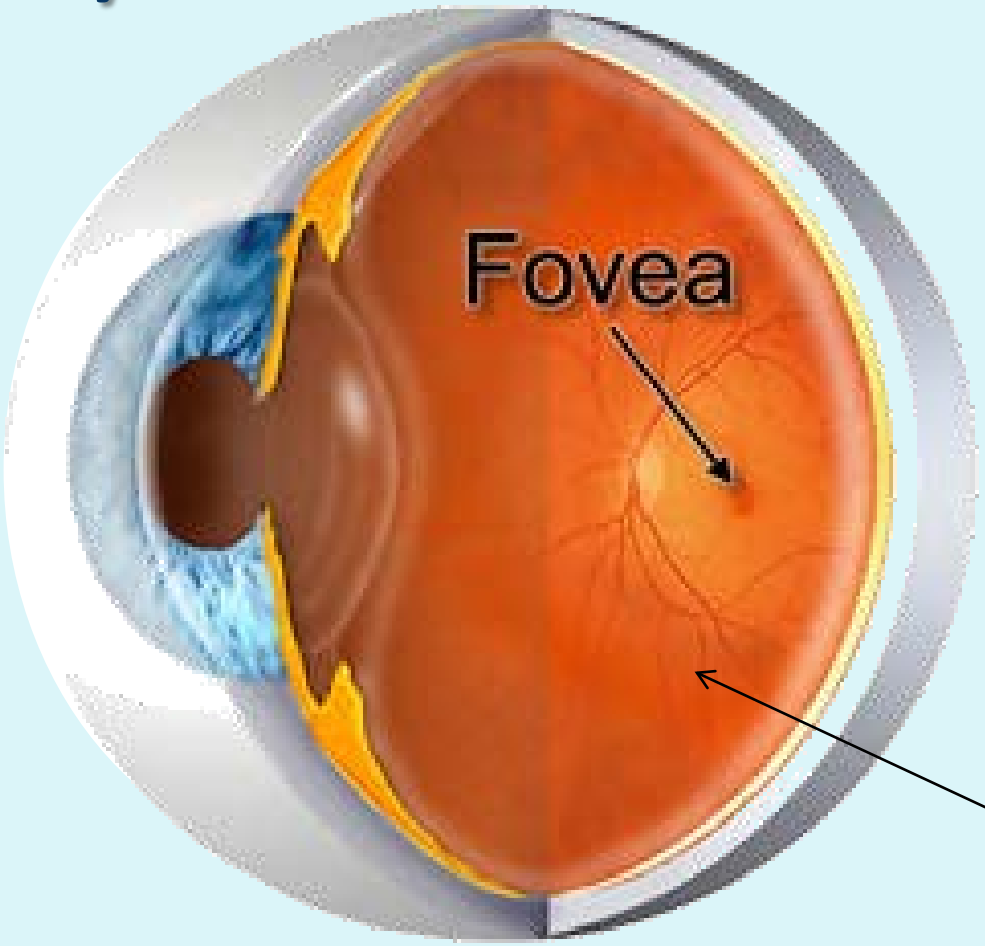
- Use passive polarising not active shutter glasses
- Disadvantages of active:
  - Heavy, uncomfortable
  - Expensive (x50!), complex, more to go wrong
  - Dimmer, *and* worse ghosting
  - Need to be switched on
  - Shuttering causes visible flicker & “beats”
  - Interocular time delays cause depth artefacts (Pulfrich effect)
  - Sacrifices (already poor) temporal resolution rather than (good) spatial resolution

In this talk:

- 1. Background on eye movements
- 2. Accommodation and convergence
- 3. Misalignments of the display
- 4. Reconstructing depth from disparity

Implications for S3D

1. Eye movements

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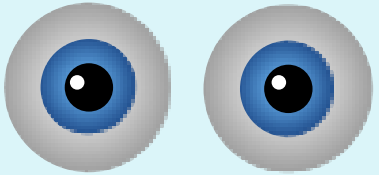
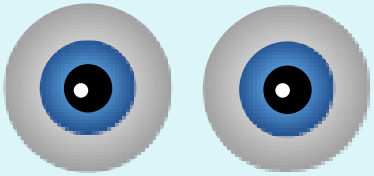
Eye movements

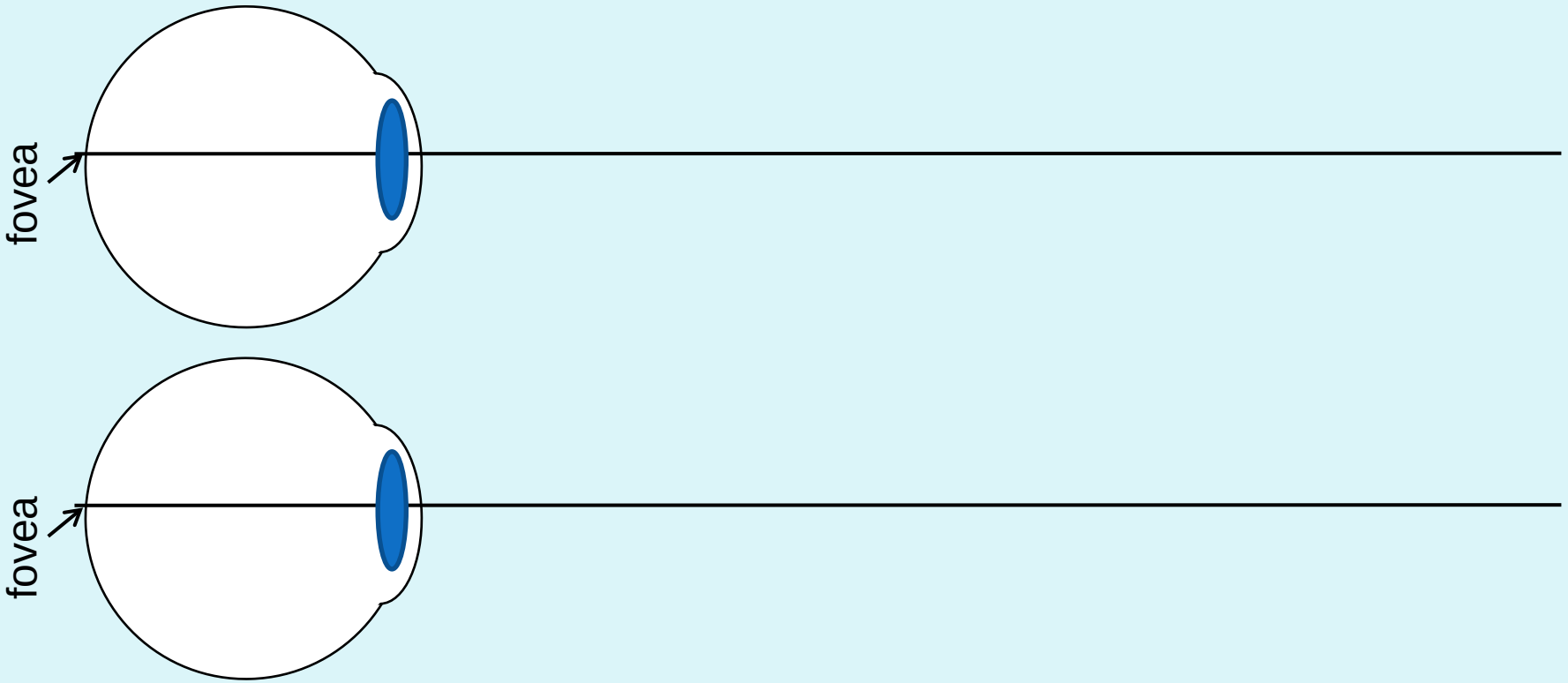
- We move our eyes all the time to point our foveas at what we're interested in.
- Can divide eye movements into version and vergence.
- **Version**: both eyes moving together, to look up, down, left, right. Fast: up to 500°/s. 2D.

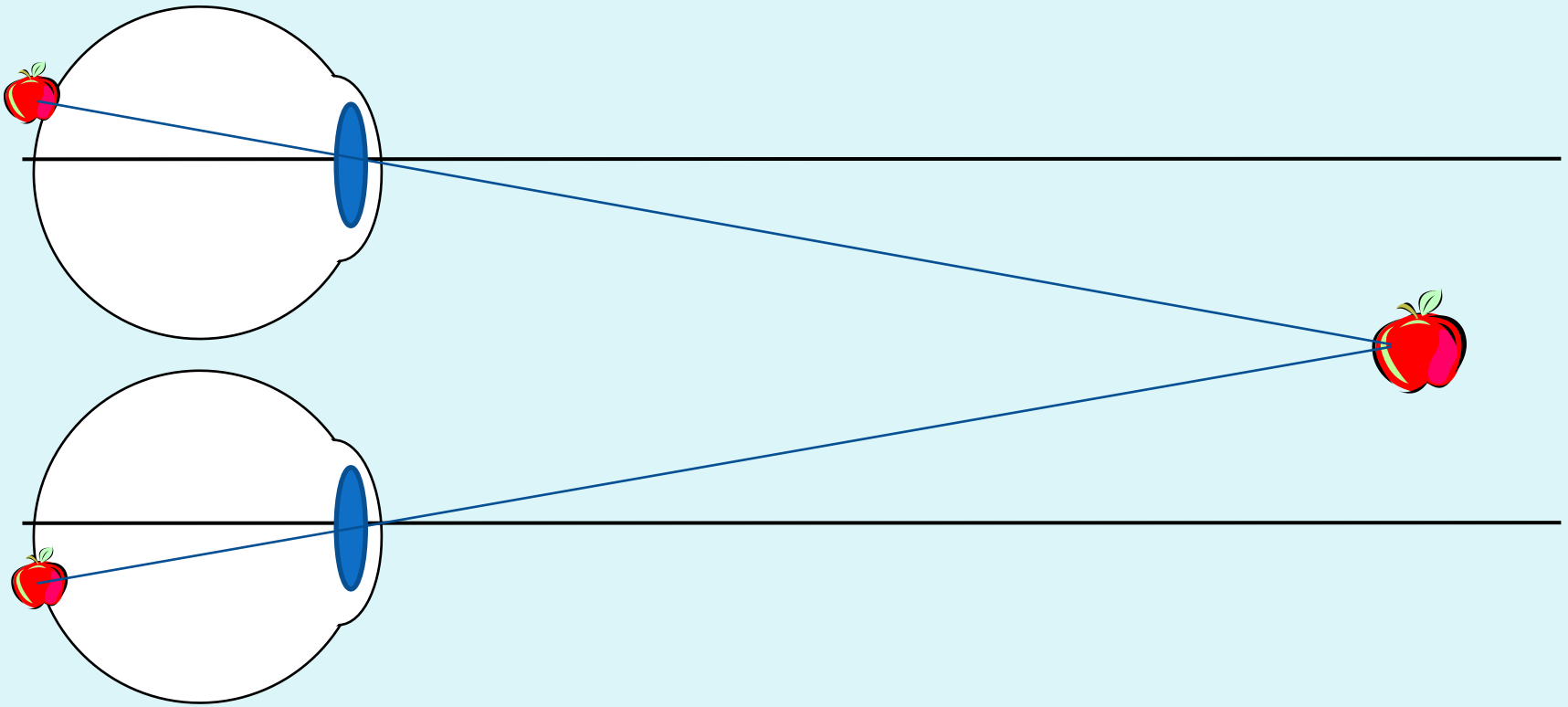


- **Vergence**: the two eyes moving in opposite directions, to look near or far. Slow: 25°/s. S3D.

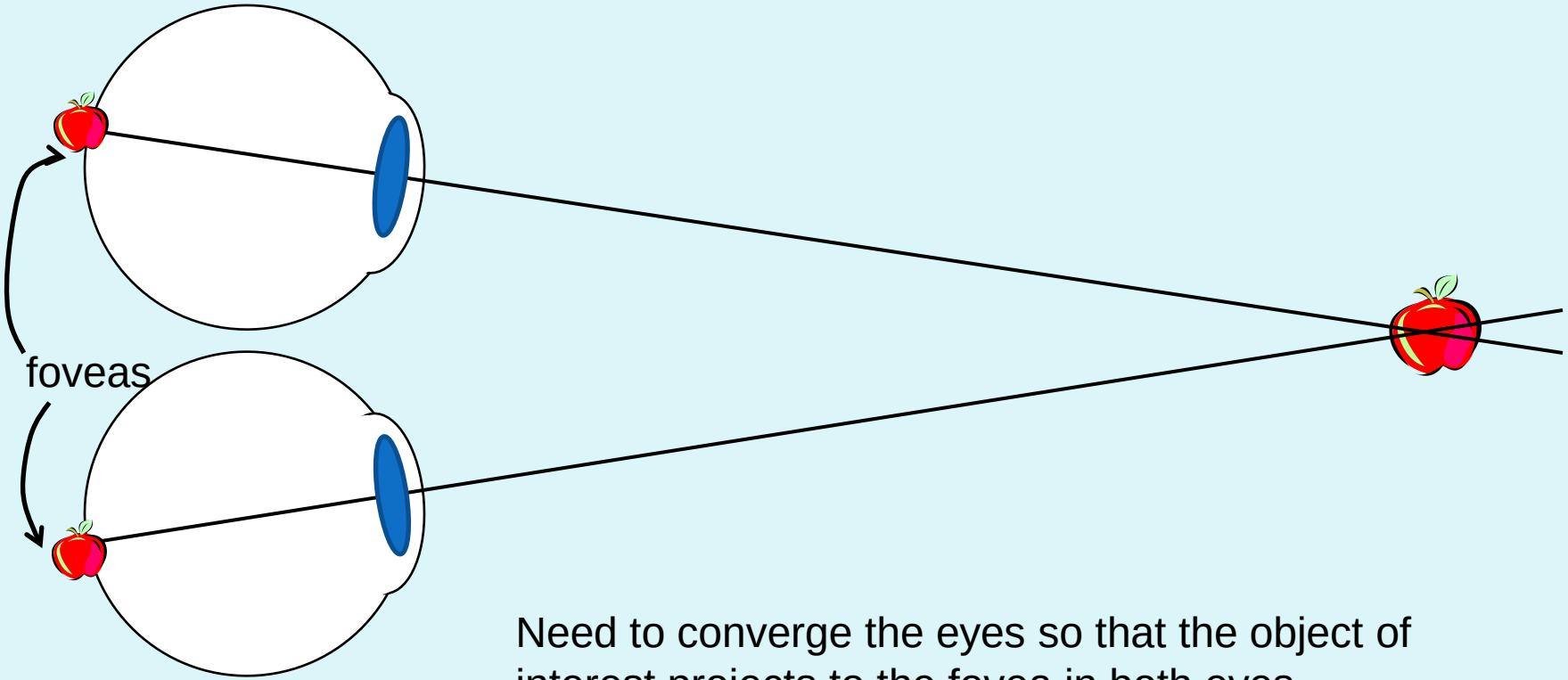


- Driven by different neuronal circuits.


fovea
fovea



Convergence

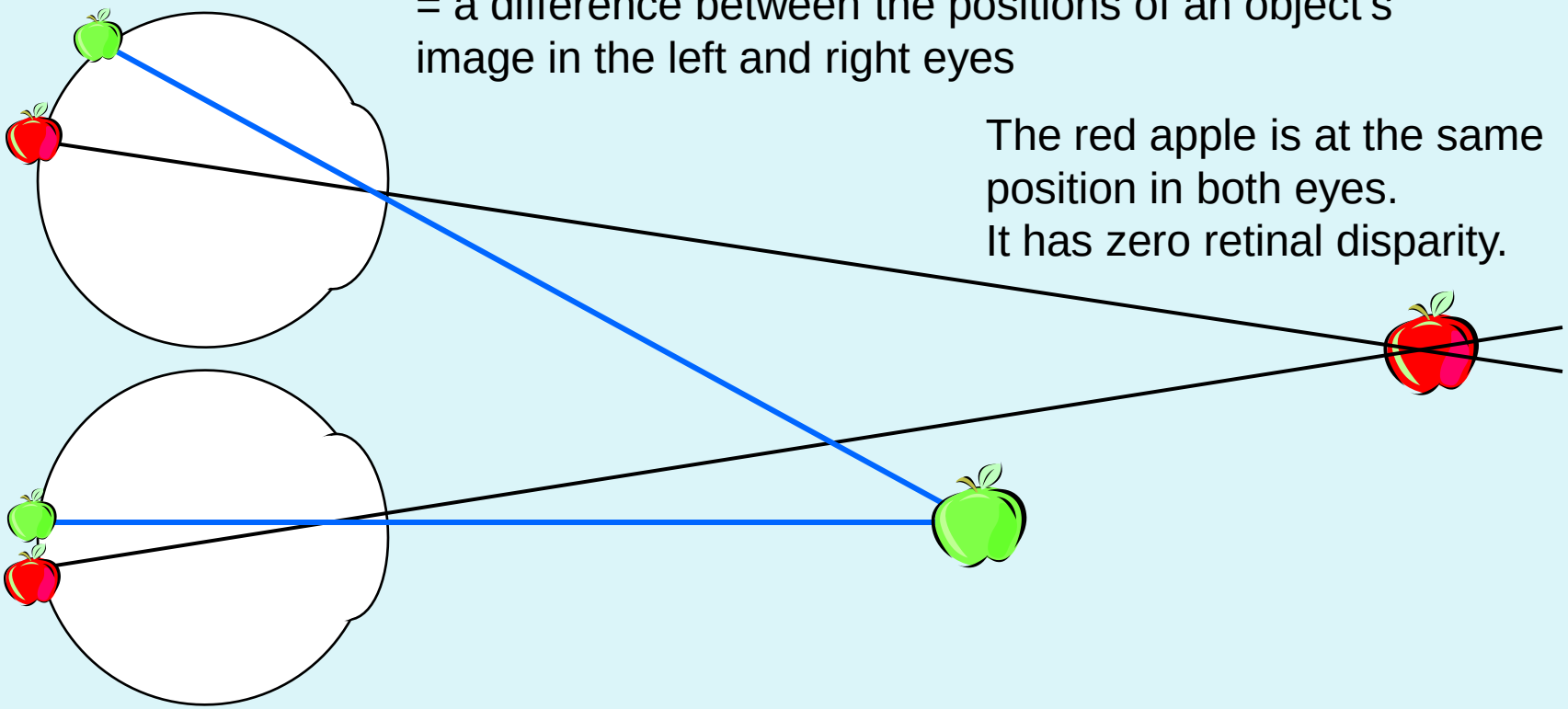


Need to converge the eyes so that the object of interest projects to the fovea in both eyes.

Retinal disparity

= a difference between the positions of an object's image in the left and right eyes

The red apple is at the same position in both eyes.
It has zero retinal disparity.



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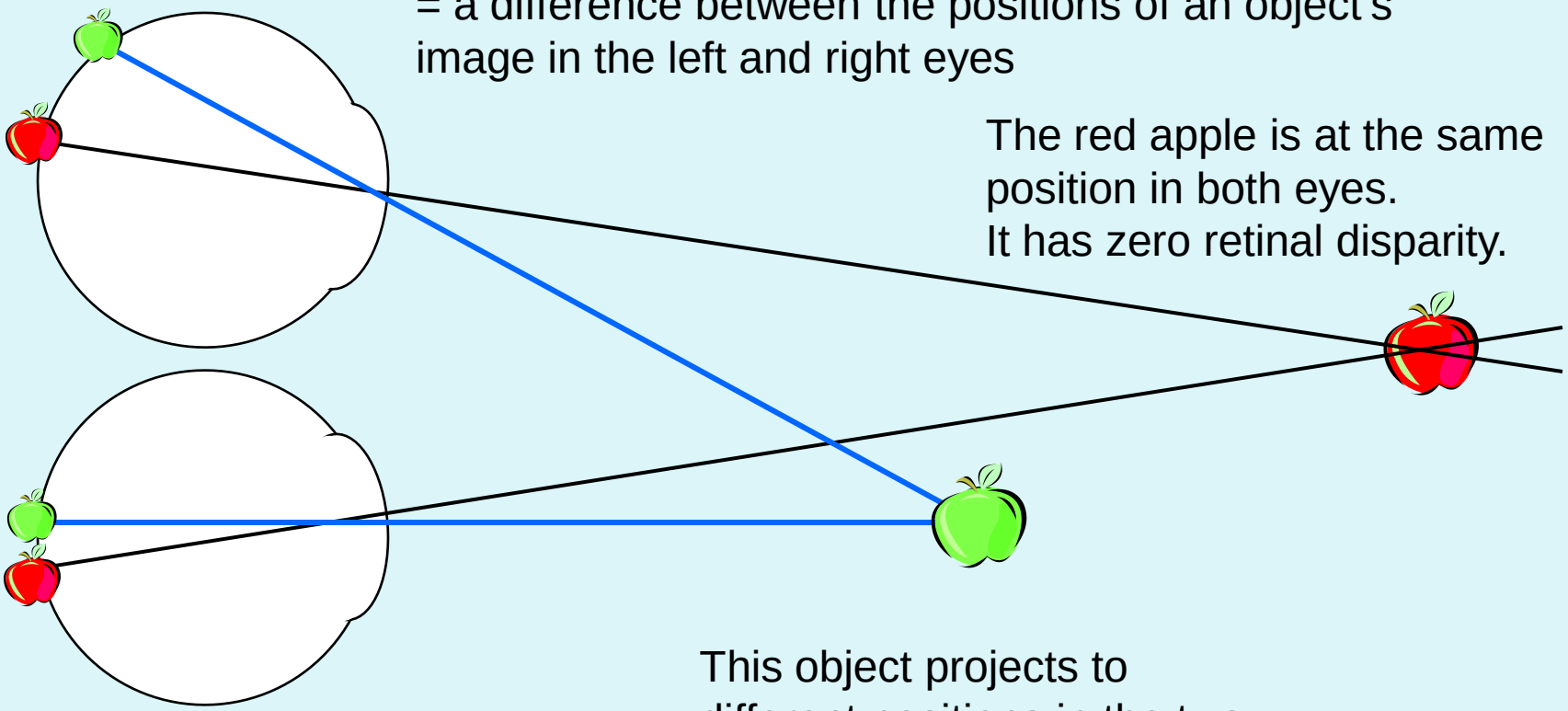
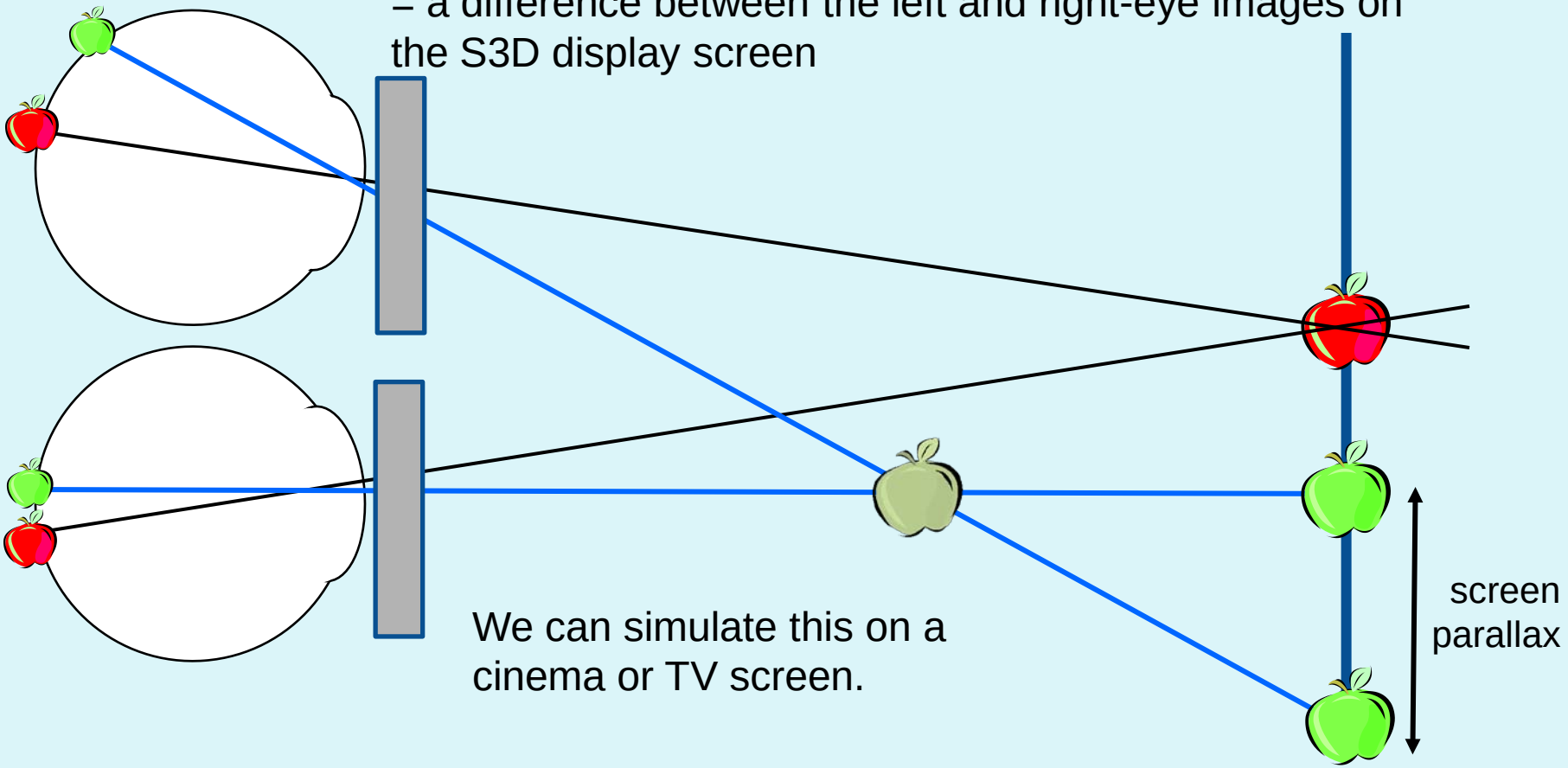


The red apple is at the same position in both eyes.
It has zero retinal disparity.

This object projects to different positions in the two eyes. It has "near" or "crossed" retinal disparity.

Screen parallax

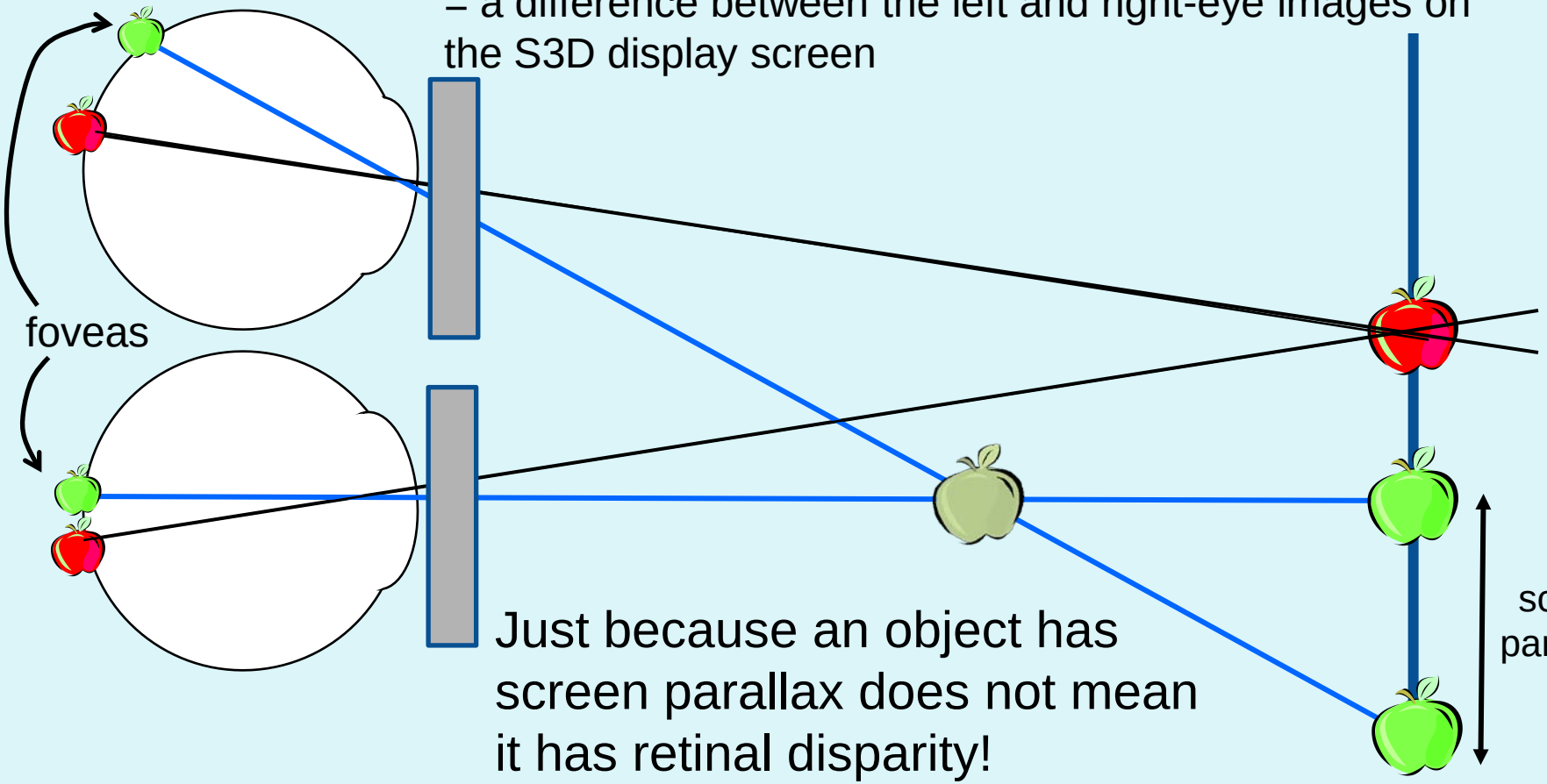
= a difference between the left and right-eye images on the S3D display screen



We can simulate this on a cinema or TV screen.

Screen parallax

= a difference between the left and right-eye images on the S3D display screen



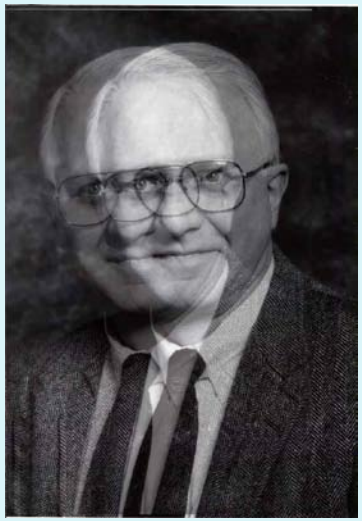
Just because an object has screen parallax does not mean it has retinal disparity!

Eye movements

- Why should the S3D industry care about eye movements?
- What the visual system receives is retinal disparity
- The mapping from screen parallax to retinal disparity depends on eye position
- The same screen parallax can result in different retinal disparities depending on eye position, and hence in a different viewer experience.

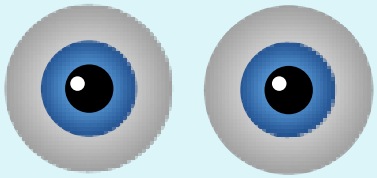
Eye movements

- Screen parallax in an object of interest generally stimulates eye movements designed to null the retinal disparity.
- This is good because we can't fuse large retinal disparities.

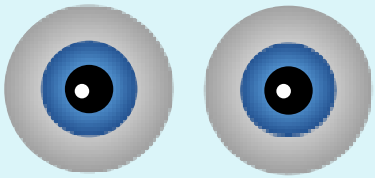


Eye movements

- 2D content demands only version eye movements as we look around the scene. Fast and easy.



- S3D content demands vergence, to look near or far. Slow and demanding.

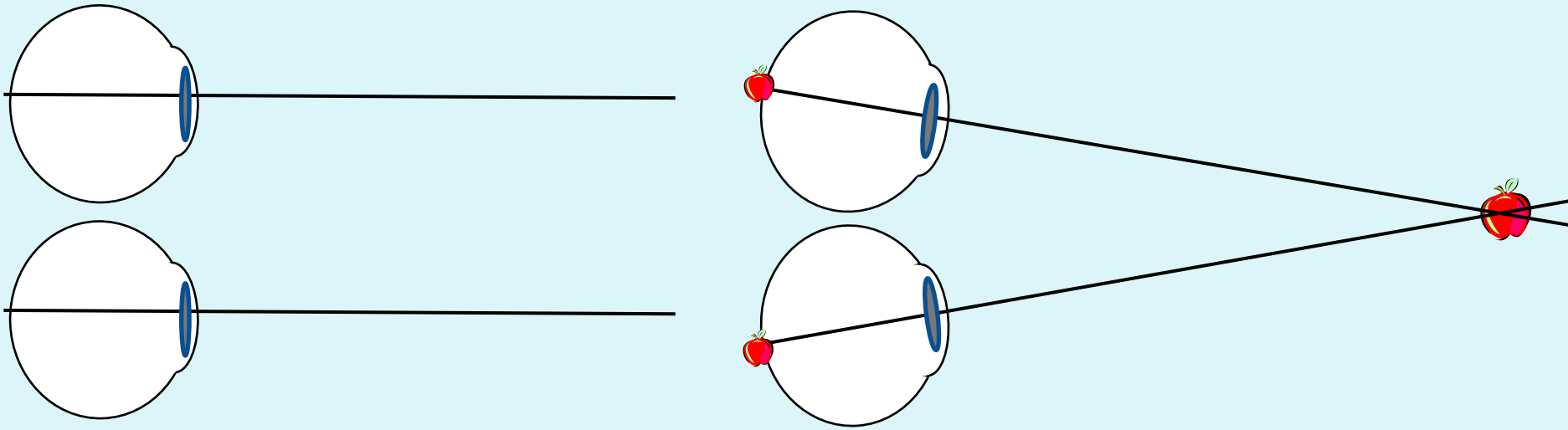


1. Eye movements: Implications for S3D

- Avoid cuts with large jumps in screen parallax.
- This will cause double vision initially, because the retinal disparities are too large to be fused.
- The viewer should then initiate a vergence movement to either converge or diverge the eyes appropriately, but this takes time.
- In natural viewing, objects don't generally just appear from nowhere!

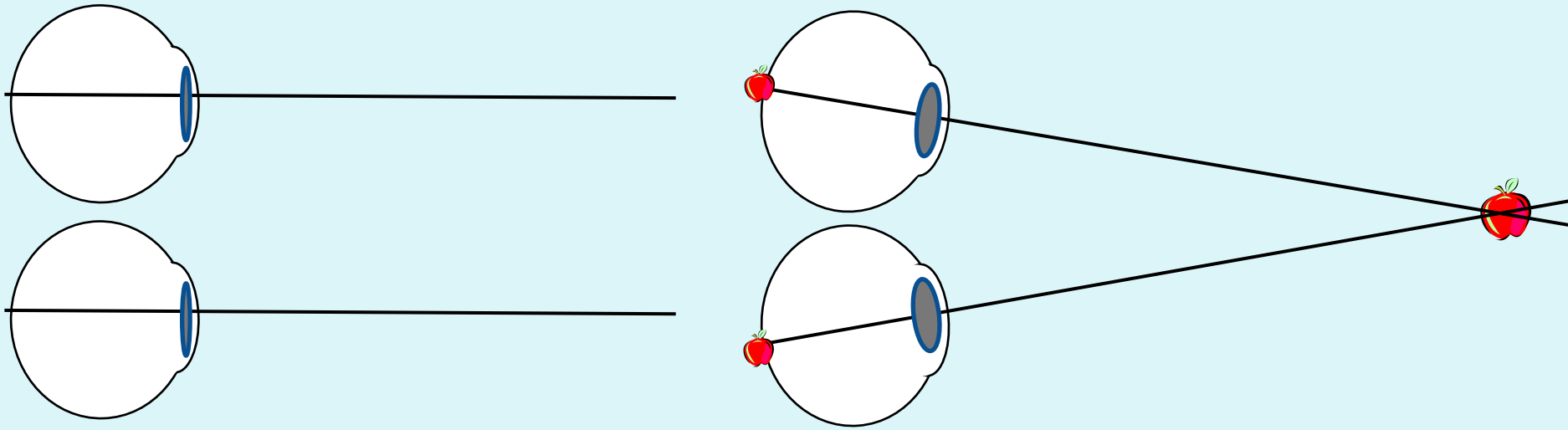
2. Accommodation & convergence

Need to converge the eyes so that the object of interest projects to the fovea in both eyes.



2. Accommodation & convergence

Need to converge the eyes so that the object of interest projects to the fovea in both eyes.
You also need to *accommodate* (focus)



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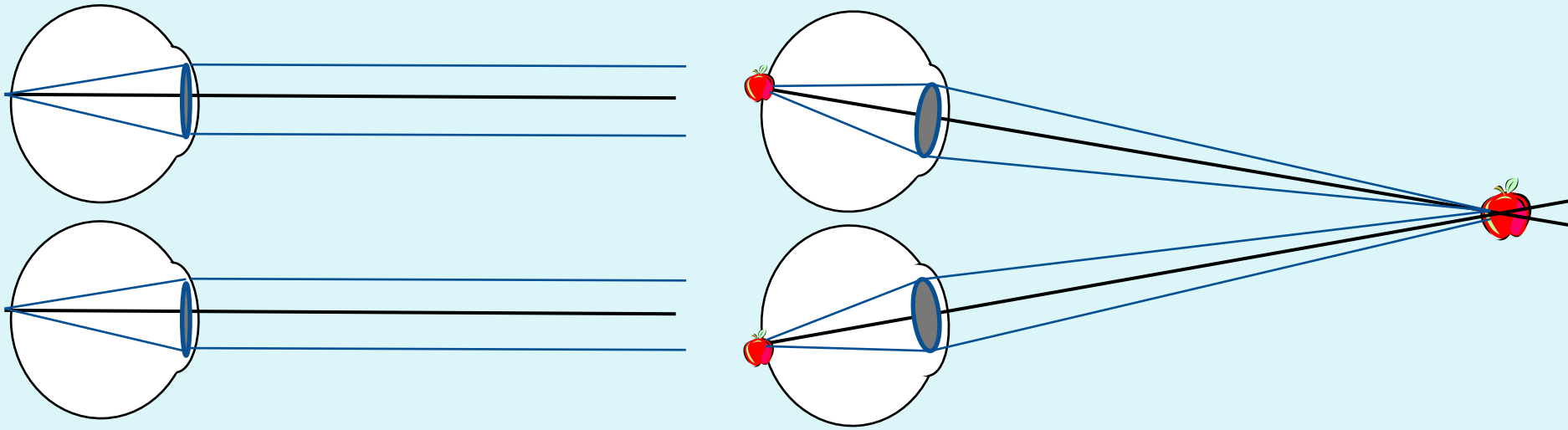
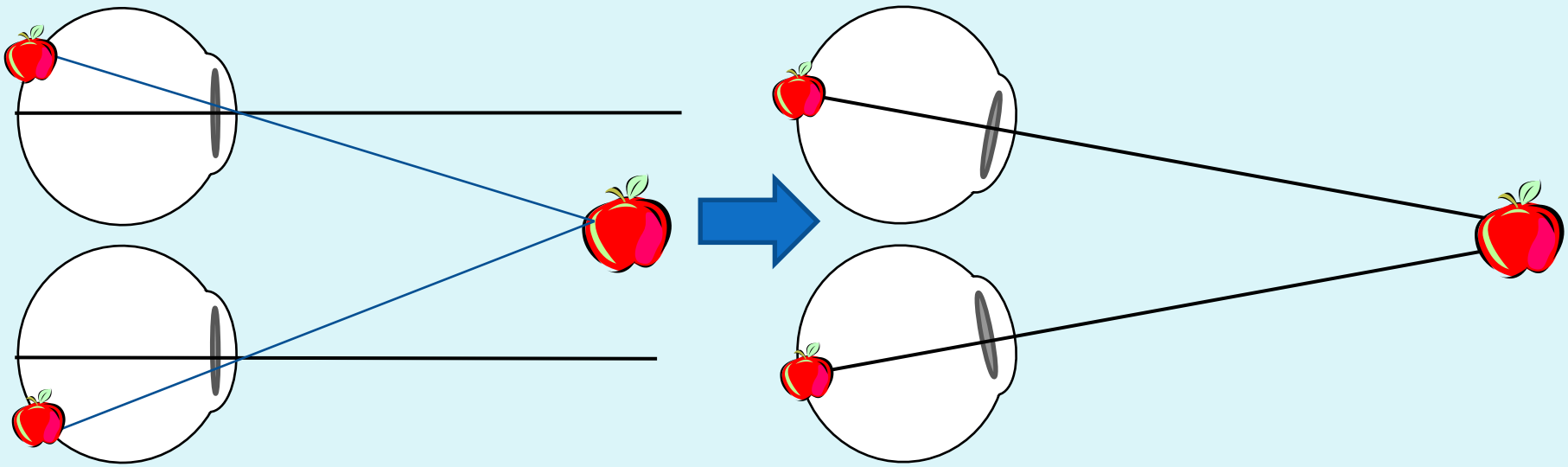


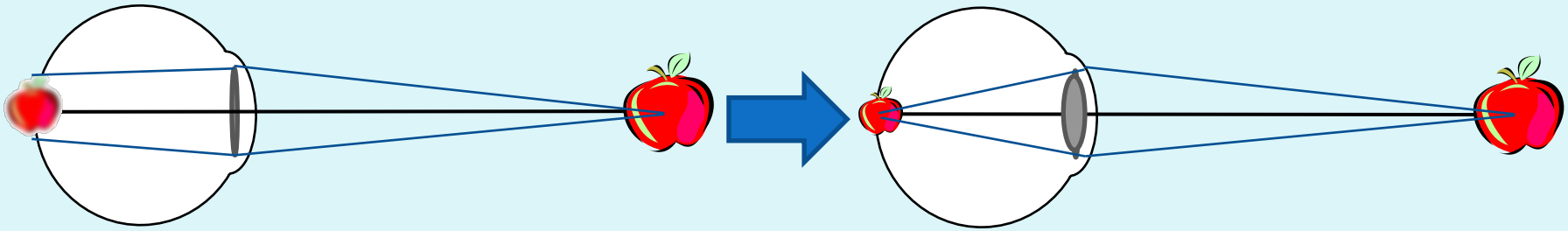
Accommodation and vergence are driven by retinal cues

Retinal disparity triggers vergence:



Accommodation and vergence are driven by retinal cues

Blur triggers accommodation:

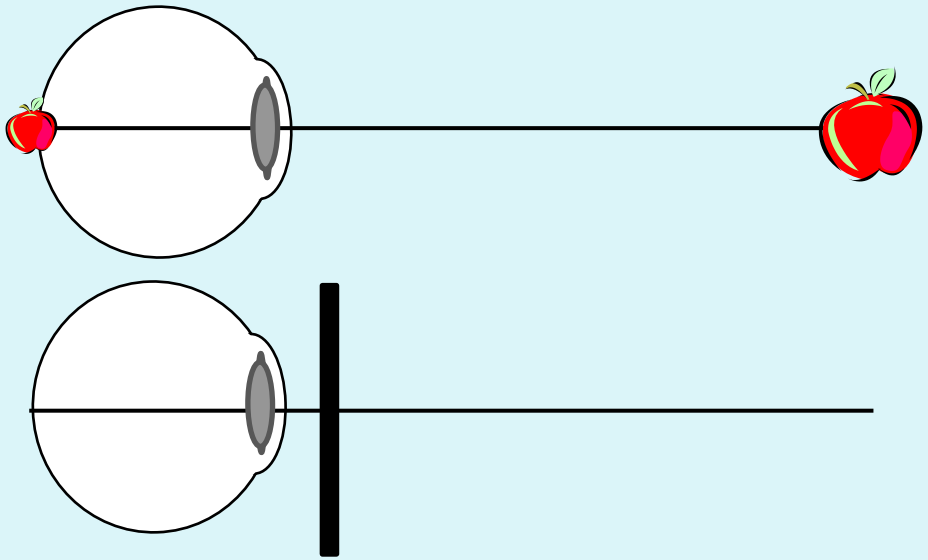


Accommodation and vergence are driven by retinal cues

- Retinal disparity triggers vergence eye movements to null the disparity.
- Retinal blur triggers accommodation of the lens to remove the blur.
- But in the real world, the right vergence and the right accommodation go together, since both depend on object distance

Accommodation and vergence are neurally coupled

- Accommodation also triggers vergence movements, and vice versa.



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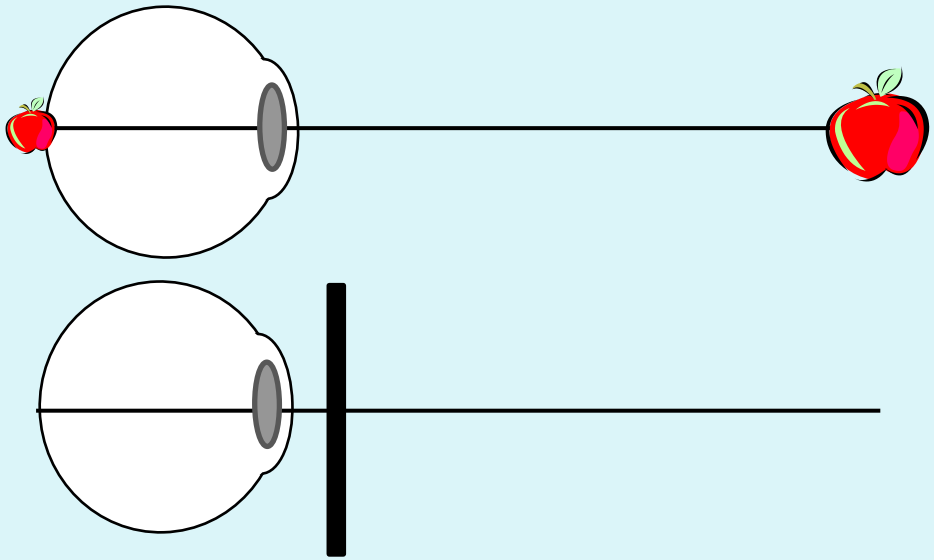
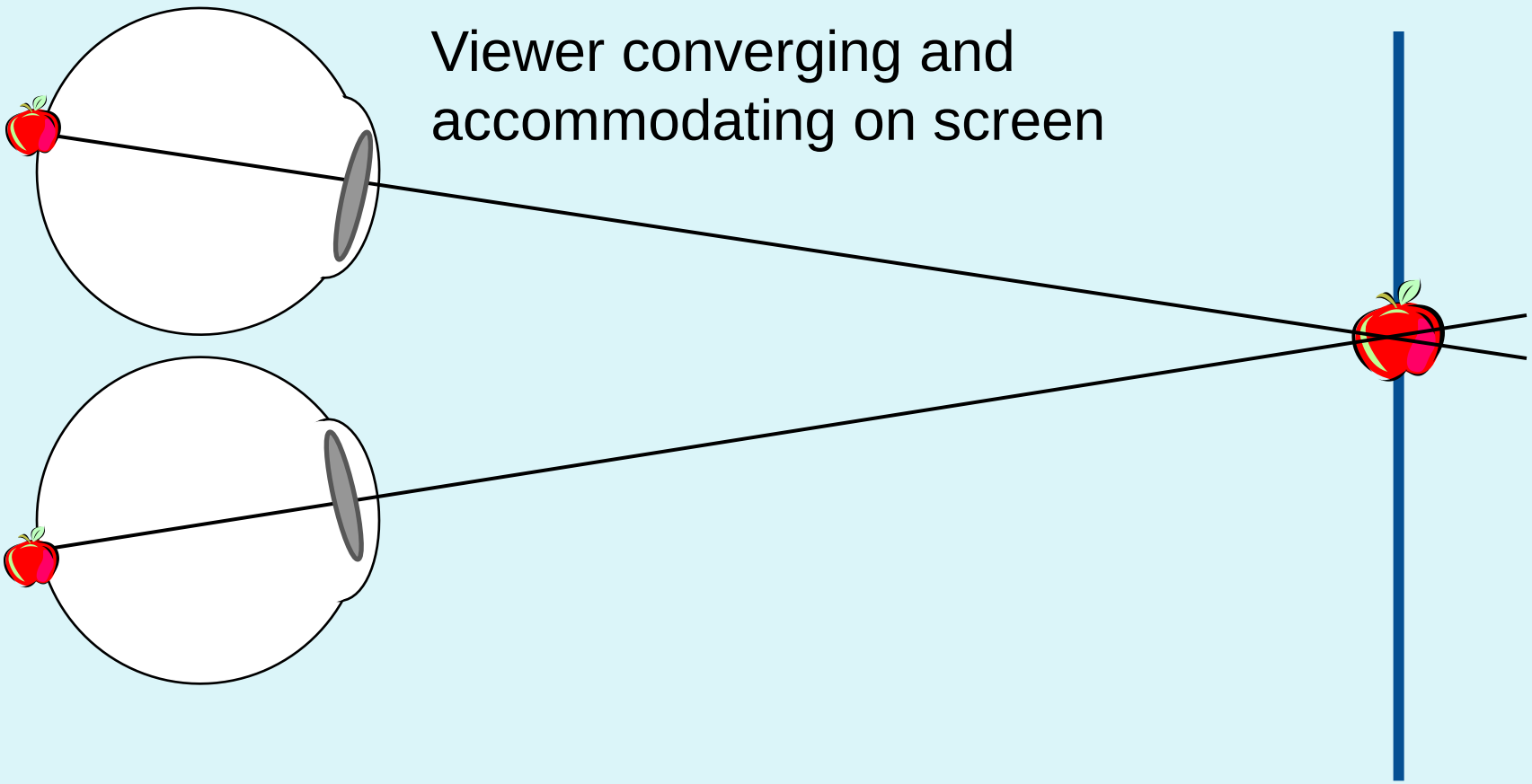


Vergence triggers accommodation



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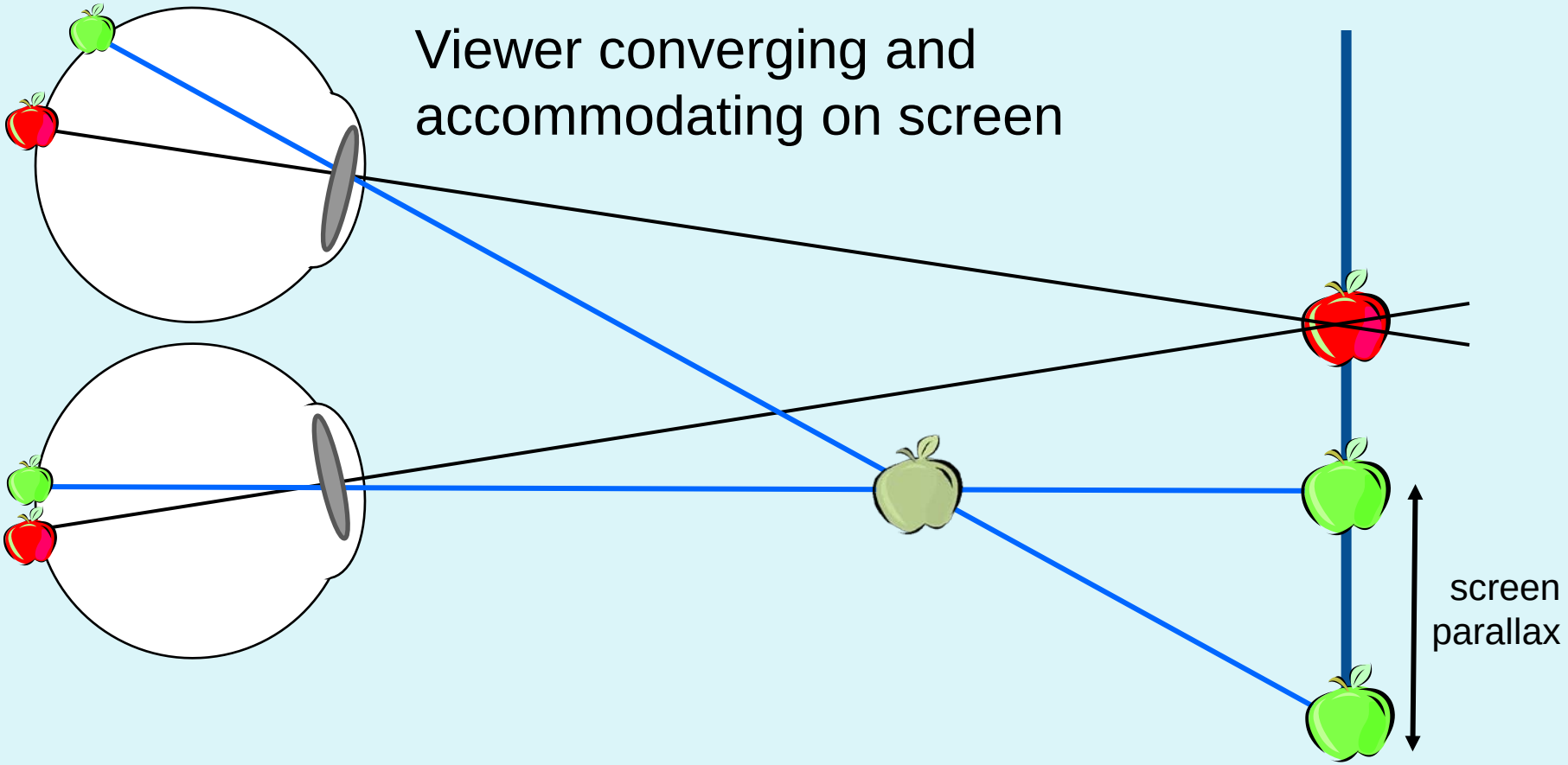


Vergence triggers accommodation

Viewer converging in front of screen

Inbuilt tendency to accommodate in front of screen.

screen parallax

Problems for S3D

- Vergence/accommodation conflict
  - Increased time to perceive stereo
  - Reduced stereoacuity
  - Increased eyestrain, fatigue, headache
- Who is most affected?
- What to do about this?

Hoffman, Girschick, Akeley, Banks (2008) **Vergence–accommodation conflicts hinder visual performance and cause visual fatigue.** *Journal of Vision*, 8(3):33

SAMSUNG

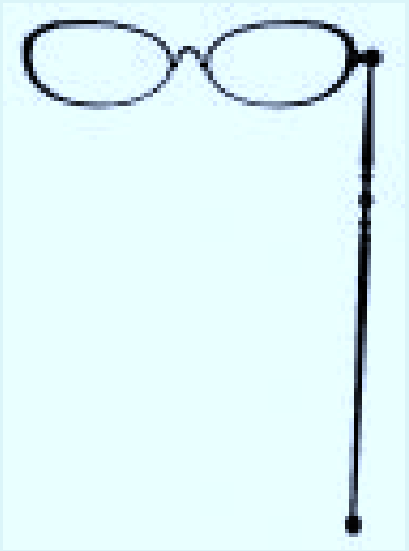
TURN ON TOMORROW

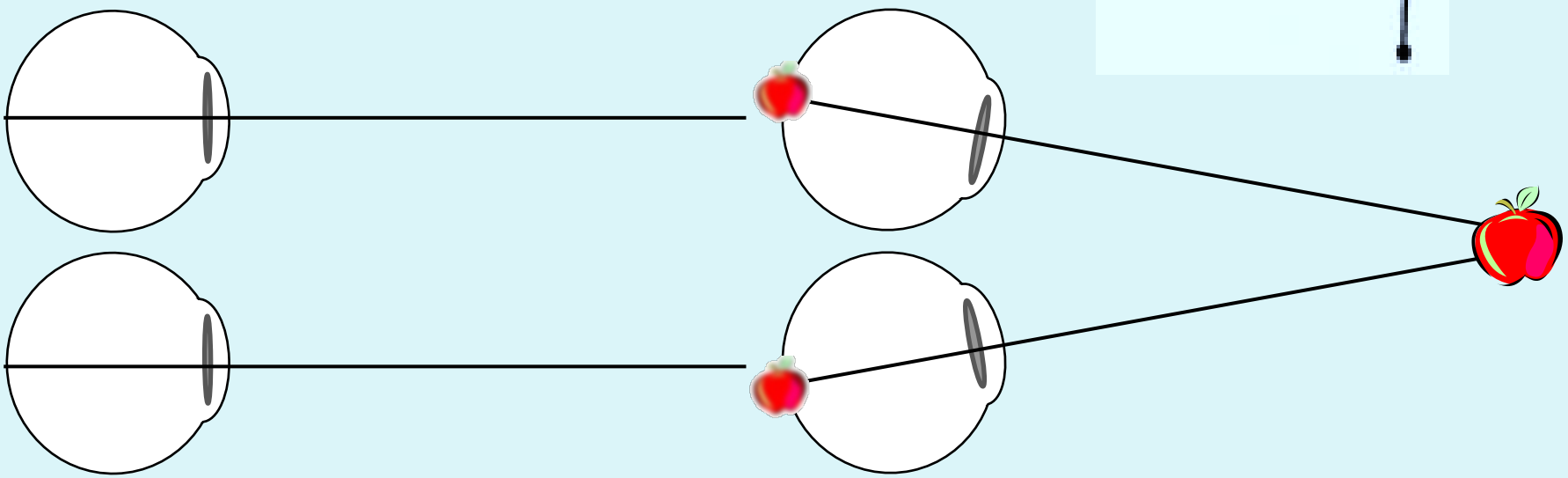
Viewing TV using the 3D function

IMPORTANT SAFETY INFORMATION. READ THE FOLLOWING WARNINGS BEFORE YOU OR YOUR CHILD USE THE 3D FUNCTION

Pregnant women, the elderly, sufferers of serious medical conditions, those who are sleep deprived or under the influence of alcohol should avoid utilising the unit's 3D functionality.

Presbyopia





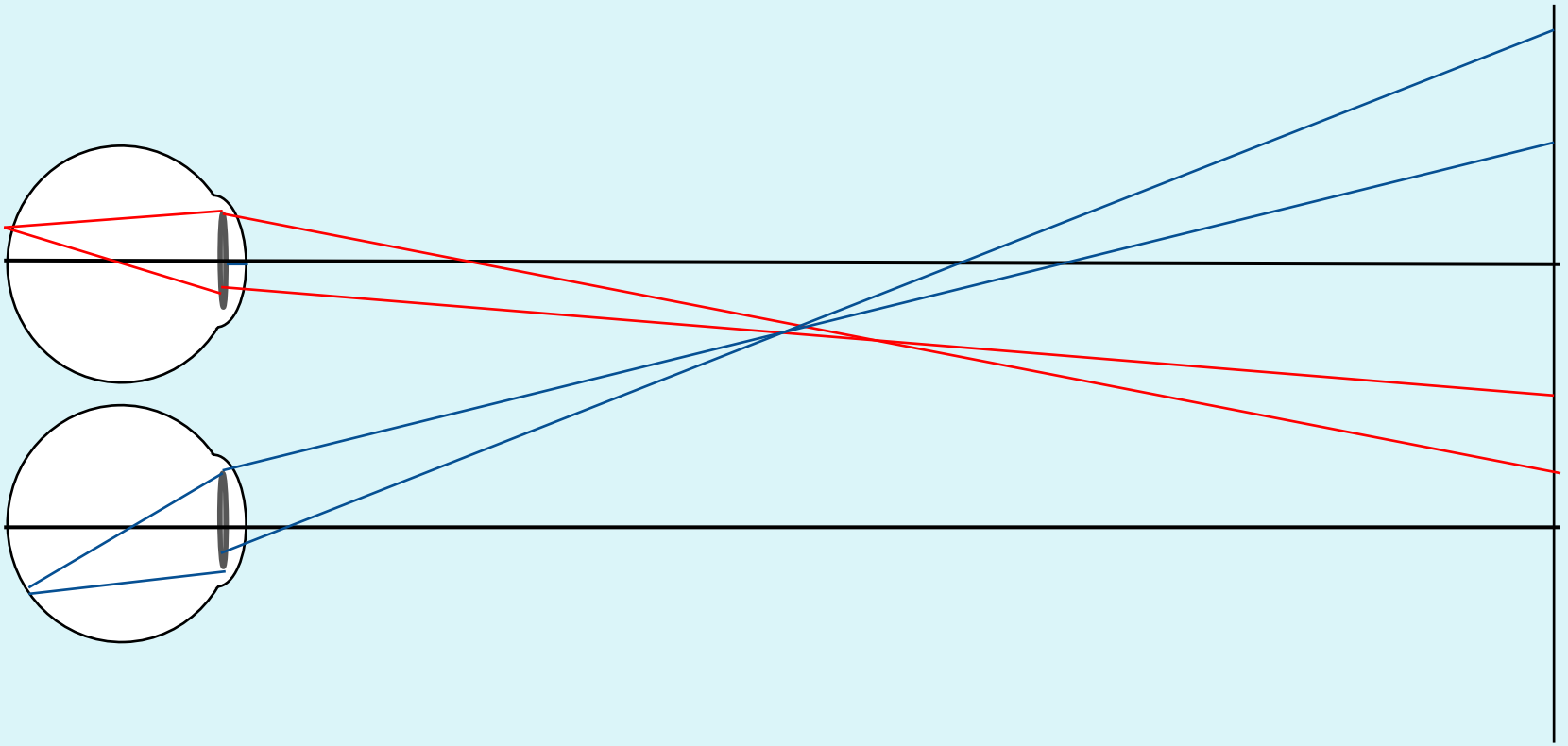
Who is most affected?

- Older people walk around all the time with a vergence/accommodation mismatch!
- We are presumably used to it.
- Mismatches in S3D should be less problematic?
- Should we be more concerned about children under the age of ~9, whose visual systems are still developing?

What can we do about it?

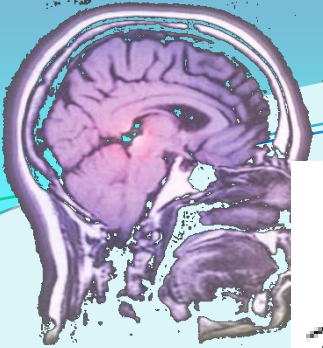
- Develop new technologies with more views!
- Disparity cue = 1 view for each eye
- Accommodation cue = several views for each eye

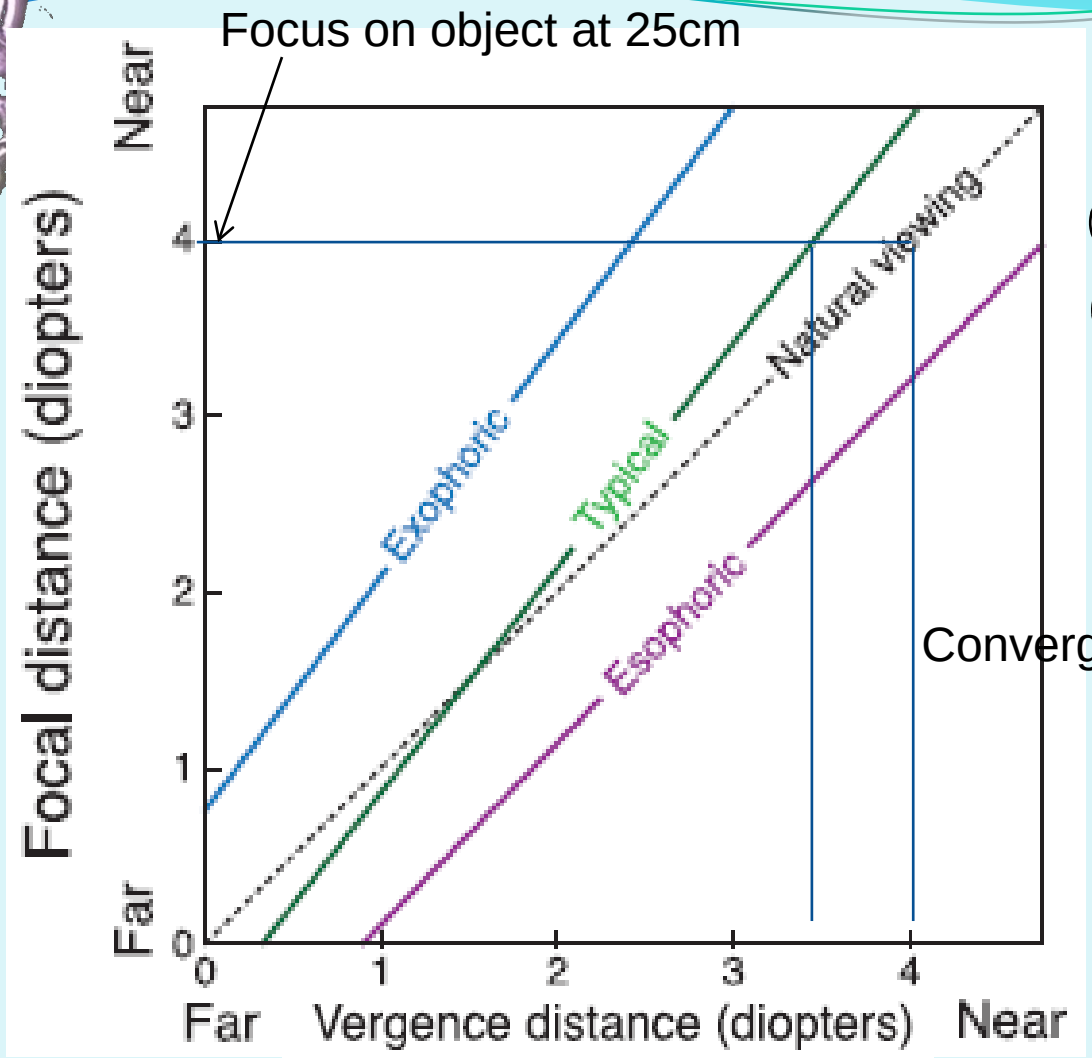
Multiple views



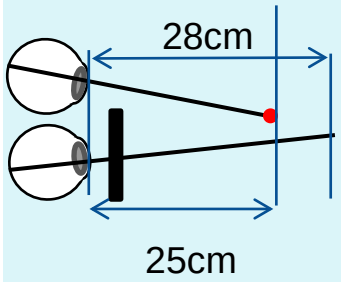
What can we do about it?

- Develop new technologies with more views!
- Use the natural properties of our visual system.
- The neural link between accommodation and vergence isn't perfect.
- For a given accommodative stimulus, we tend to converge slightly too little at short distances (~<1m) and slightly too much at far distances (>1m).

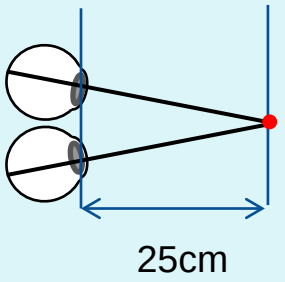




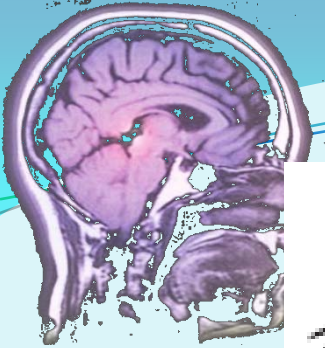
<1m: Natural tendency to underconverge



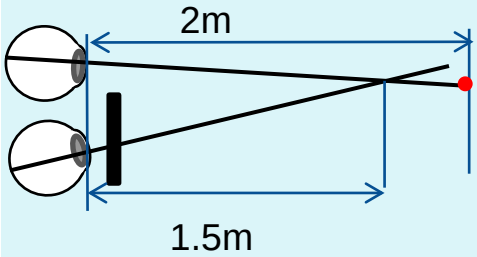
Converge on object at 25cm

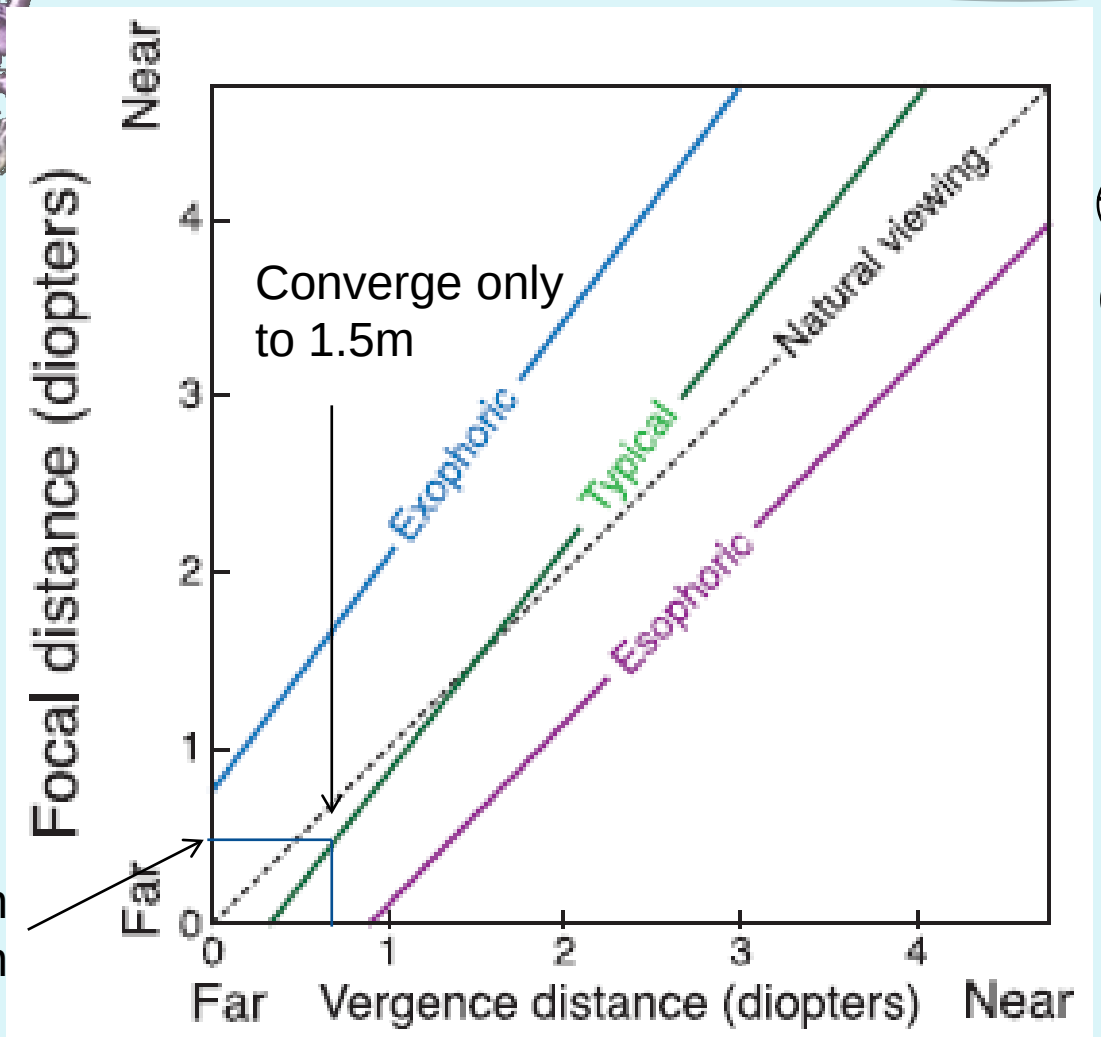


Shibata, Kim, Hoffman, Banks (2011) **The zone of comfort: Predicting visual discomfort with stereo displays**. *Journal of Vision*, 11(8):11, 1-29



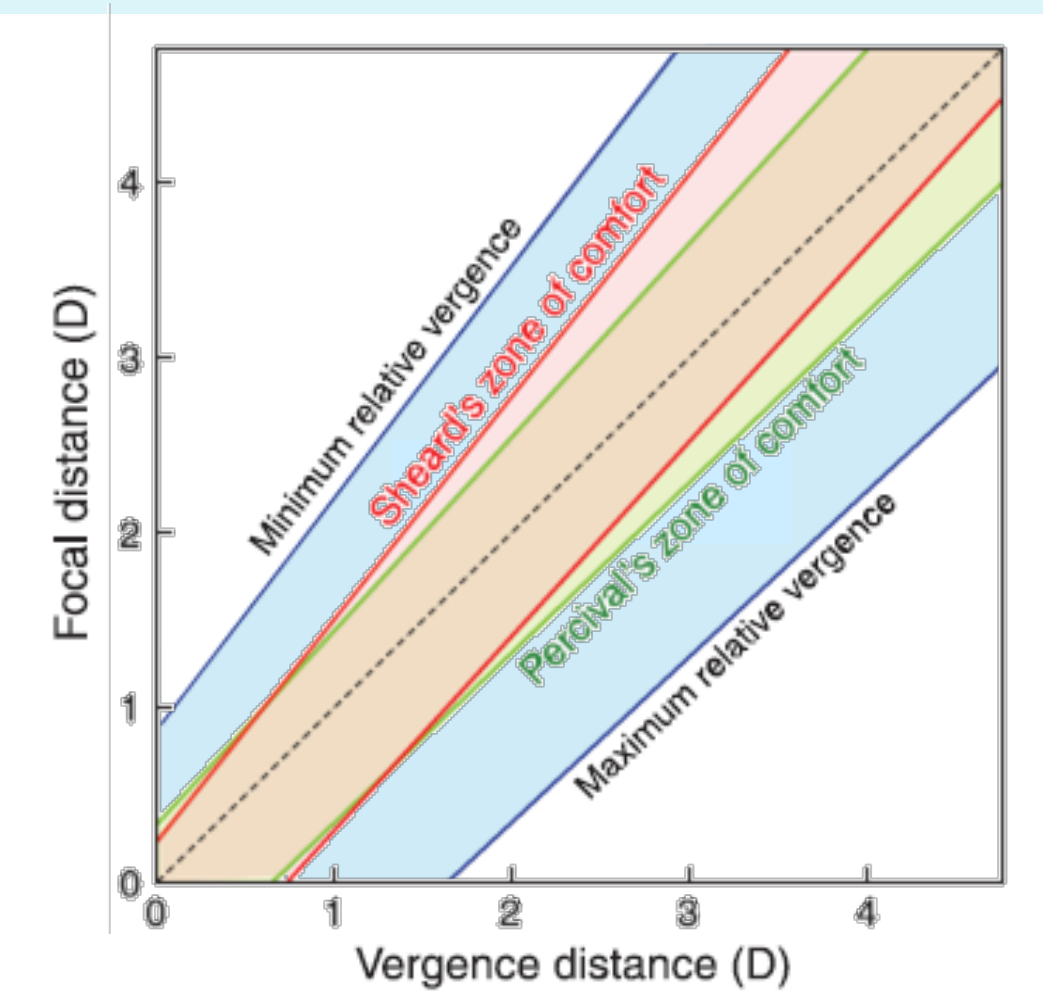
>1m: Natural tendency to overconverge





Focus on object at 2m

Shibata, Kim, Hoffman, Banks (2011) **The zone of comfort: Predicting visual discomfort with stereo displays**. *Journal of Vision*, 11(8):11, 1-29



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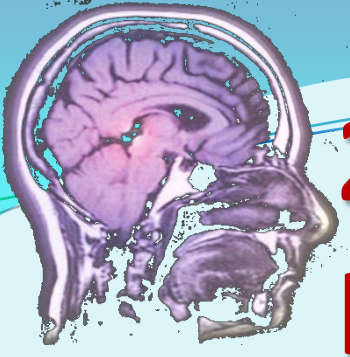
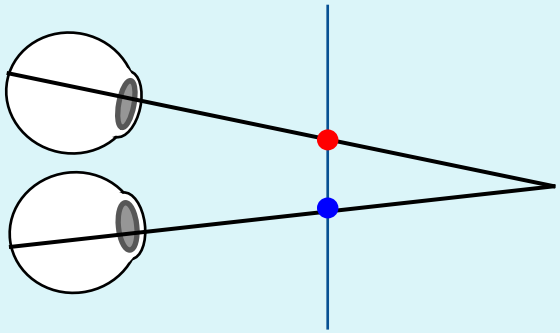


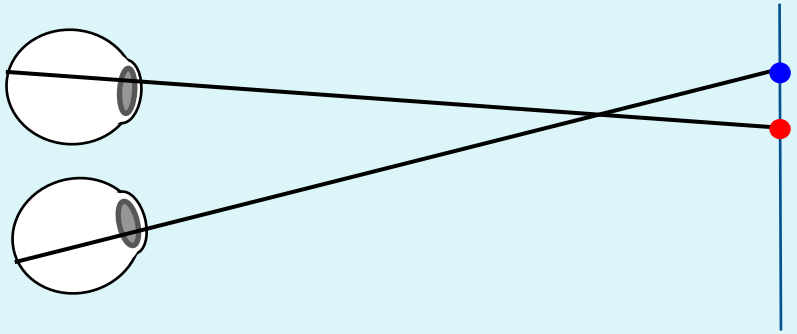
2. Accommodation/vergence: Implications for S3D

Near, <1m:
Underconverging is more natural & more comfortable.



Mobile devices, PCs:
Put more content behind the screen.

Far, >1m:
Overconverging is more natural & more comfortable.

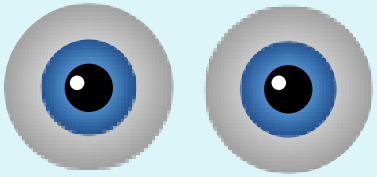


Cinema, TV:
Put more content in front of the screen.

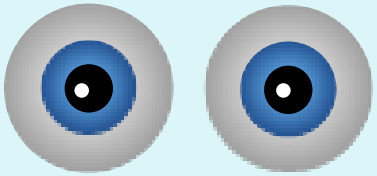
3. Misalignments

Natural eye movements

Version:



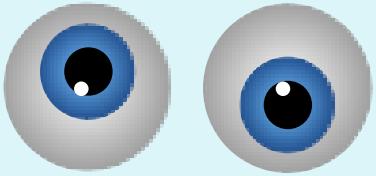
Vergence:



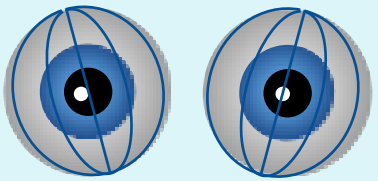
For looking around the world, at near and far objects.

Unnatural eye movements

Vertical vergence:



Cyclovergence:

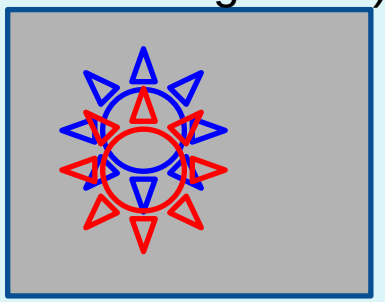


For coping when everything seems to have gone wrong!

3. Misalignments

- S3D systems have to be perfectly aligned.
- Misalignments will trigger corrective eye movements.

Image on screen (vertical misalignment)



If viewed with normal eye position:

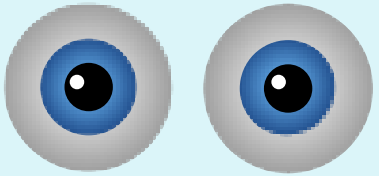
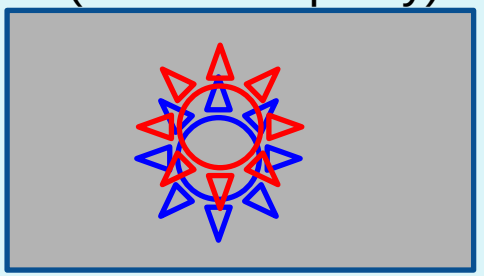
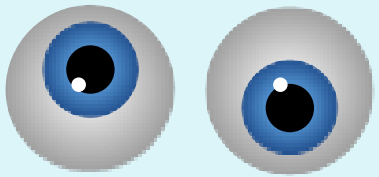


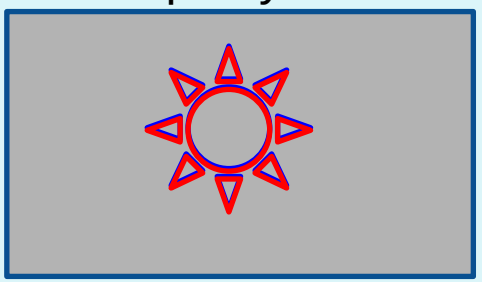
Image on retina (vertical disparity)



This triggers vertical vergence movement:



Nulls disparity on retina.



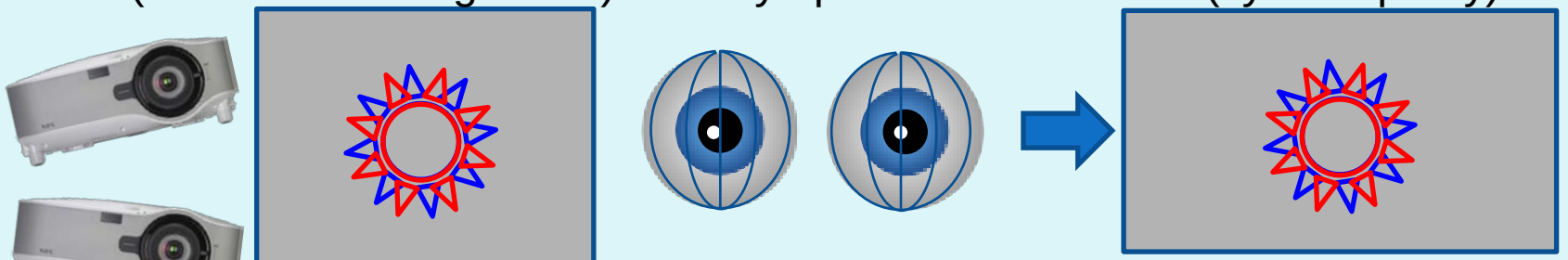
Misalignments

- S3D systems have to be perfectly aligned.
- Misalignments will trigger corrective eye movements.

Image on screen (rotational misalignment)

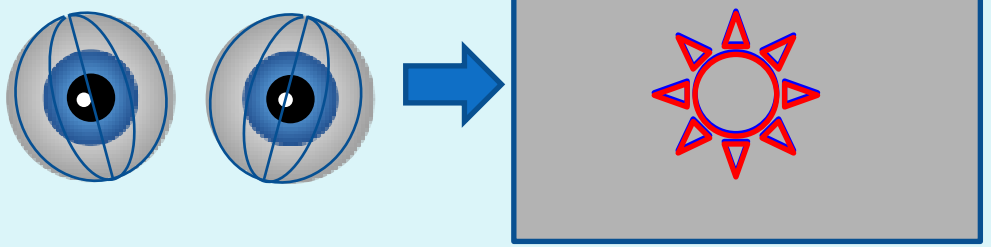
If viewed with normal eye position:

Image on retina (cyclodisparity)



This triggers cyclovergence movement:

Nulls disparity on retina.



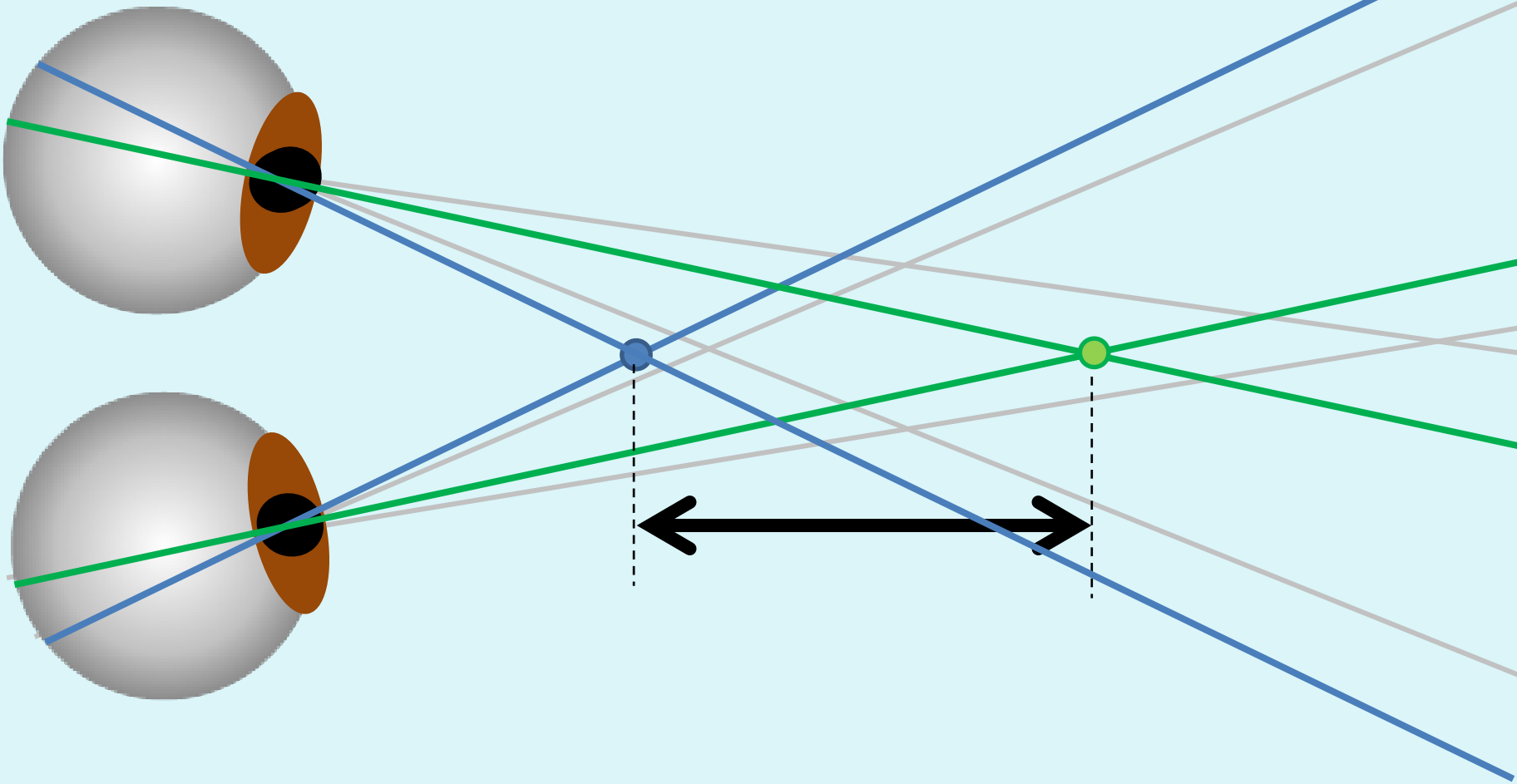
3. Misalignments: Implications for S3D

- Misalignments create eyestrain and fatigue.
- But they are easy (in principle!) to avoid.

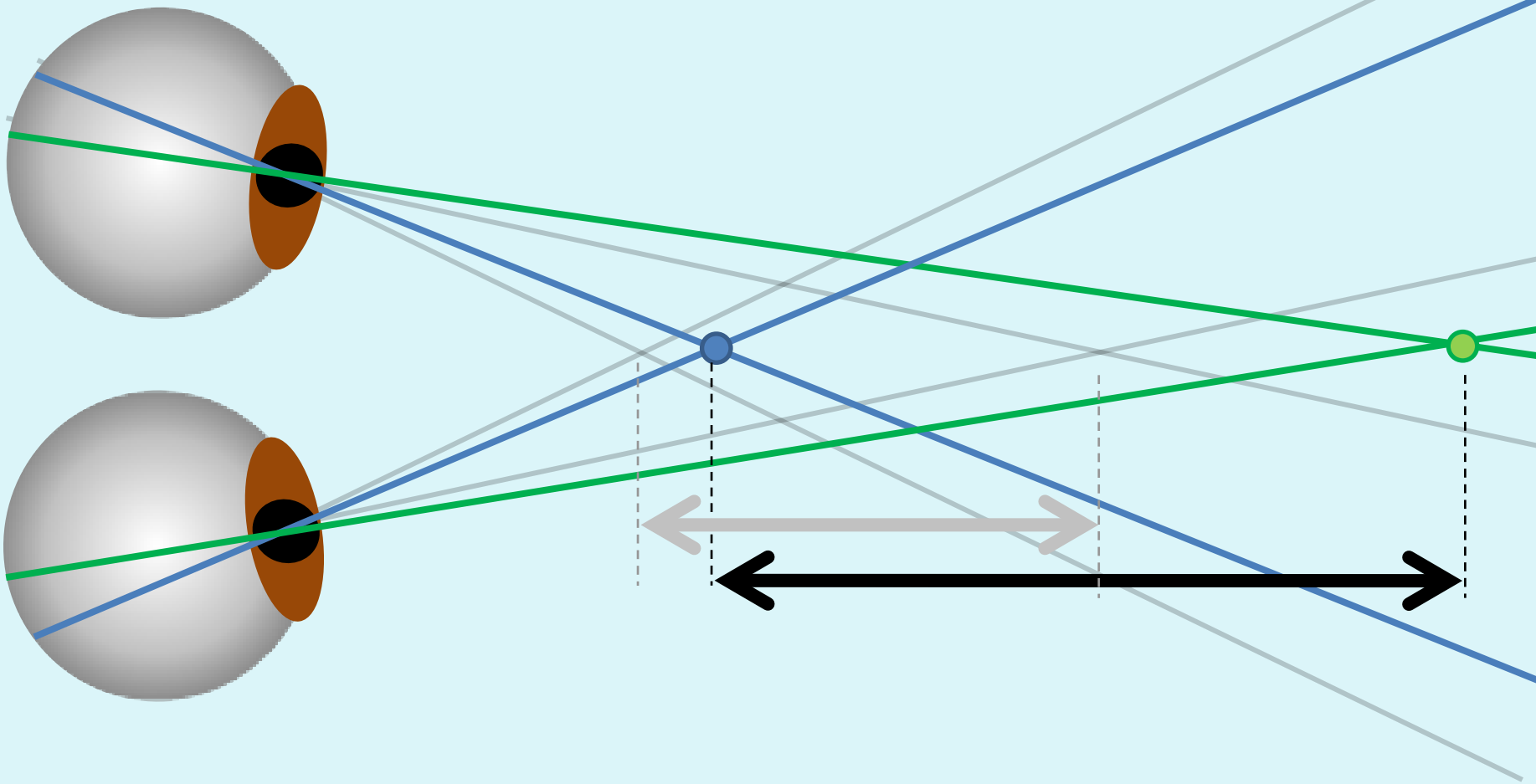
4. Reconstructing depth from disparity

- Disparity is not depth.
- The mapping from screen parallax to retinal disparity depends on eye position & viewing distance, angle of view etc.
  - This mapping is done by physics.
- The mapping from retinal disparity (an angle) to physical distance (a distance) depends on eye position.
  - This mapping is done by your brain.

From disparity to depth

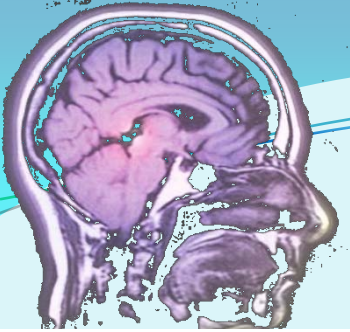


From disparity to depth

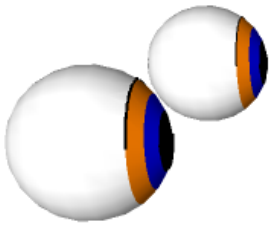


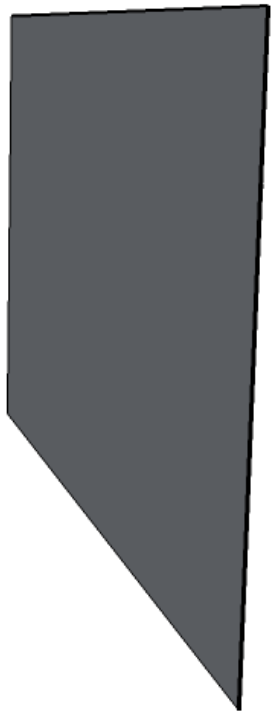
4. Reconstructing depth from disparity

- In order to reconstruct depth (metres) from disparity (deg), your brain needs to know where your eyes are pointing.
  - Oculomotor information
    - “feeling” where your eyes are
  - Retinal information
    - deducing where your eyes are simply from the pattern of disparities on the retina
    - mainly from *vertical* retinal disparities



Reproducing reality means no vertical parallax





Reproducing reality means no vertical parallax

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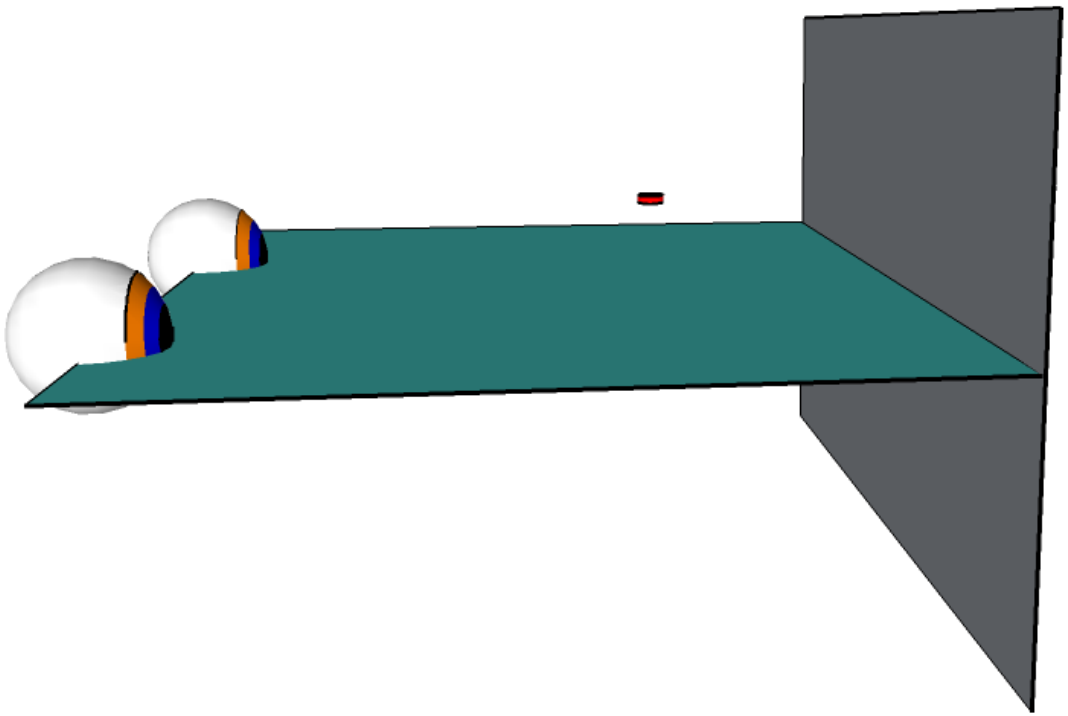

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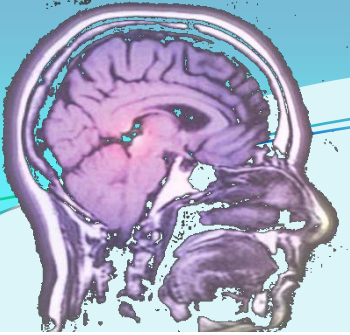
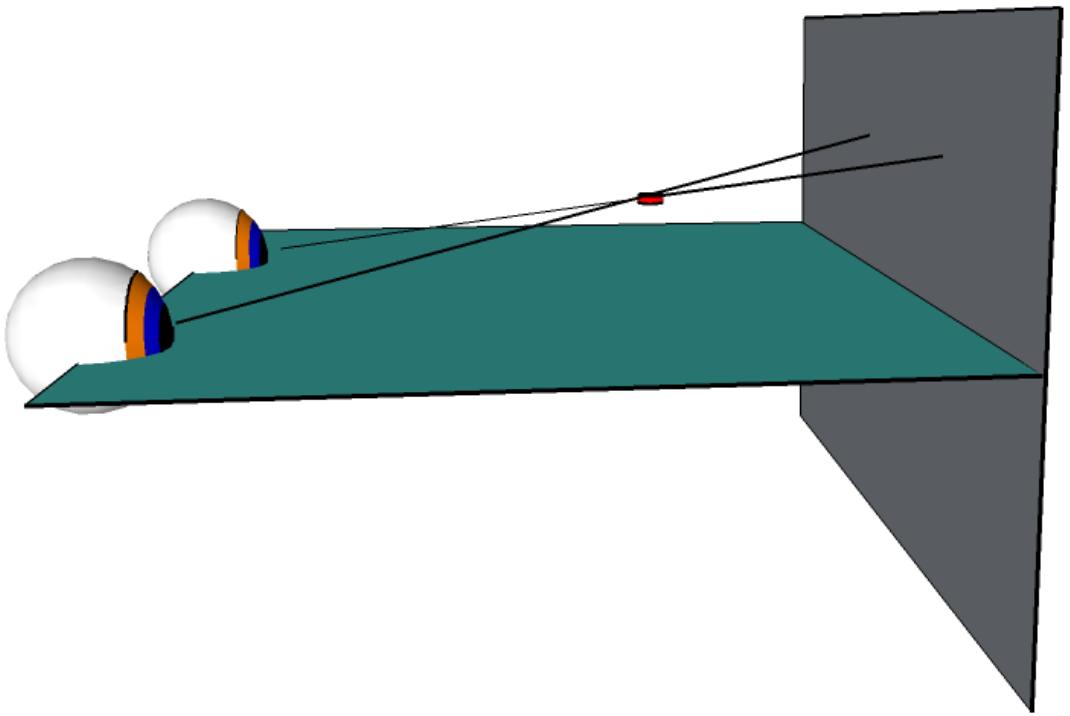


Reproducing reality means no vertical parallax



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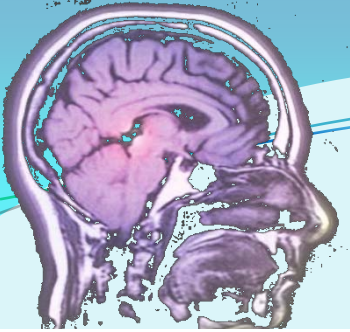
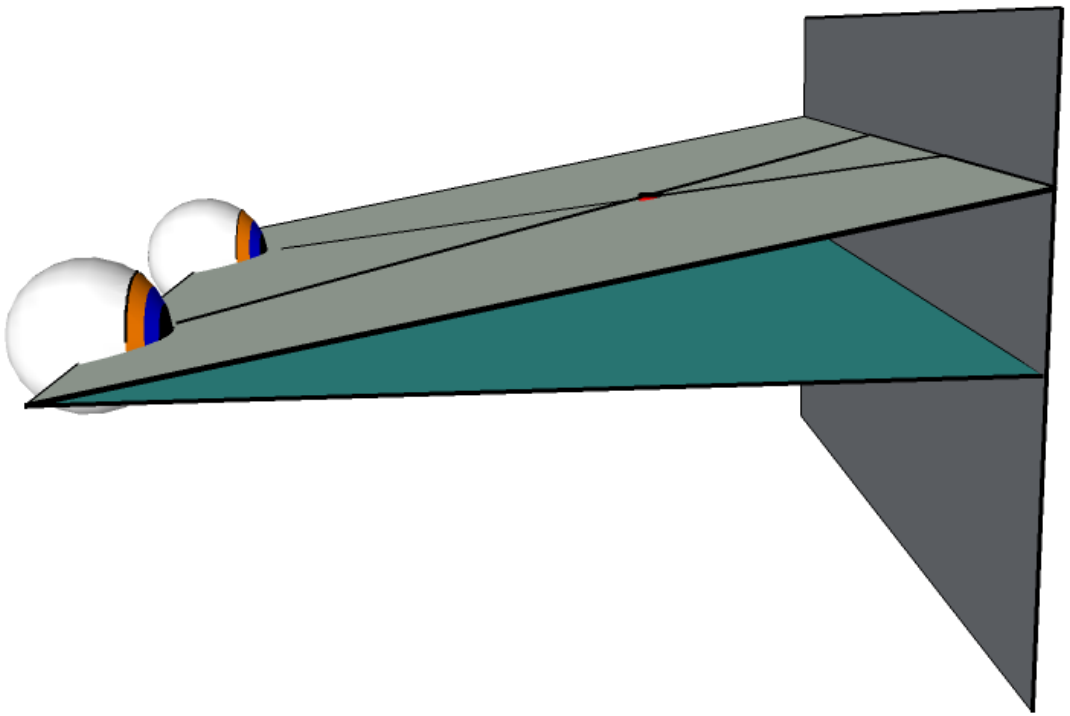


Reproducing reality means no vertical parallax

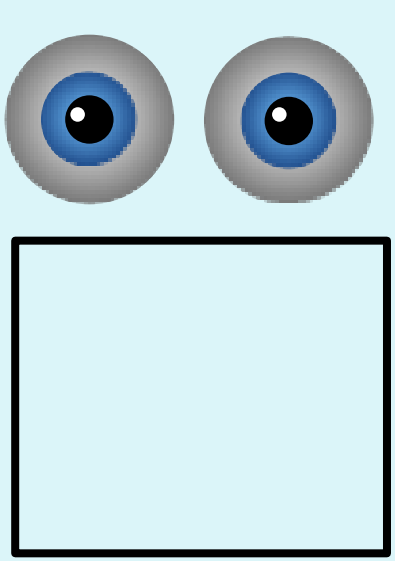


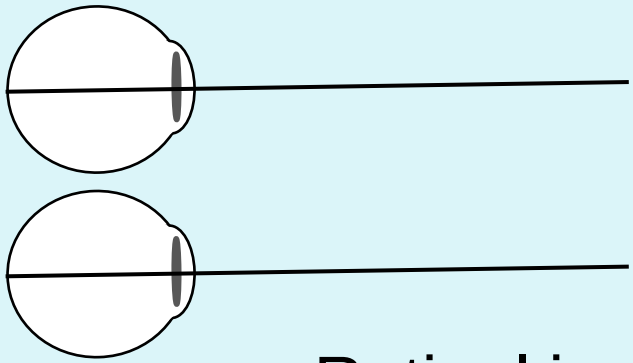
(Screen) parallax is not (retinal) disparity

- Reproducing reality means no vertical parallax on the screen
- But there may still be vertical disparity on the retina.

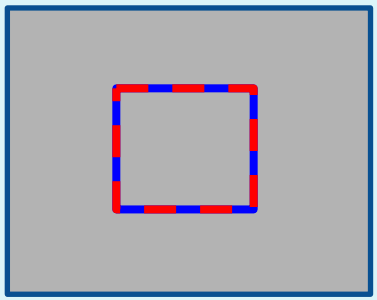
Eyes looking into distance

- Imagine looking at a square at optical infinity.





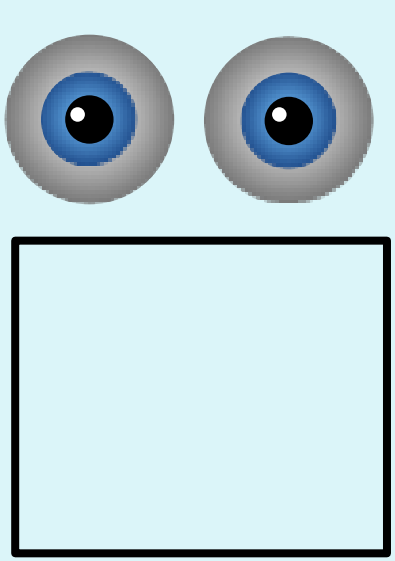
Retinal images

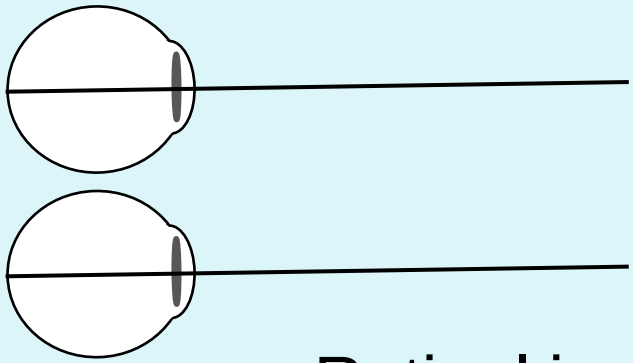


Zero disparity

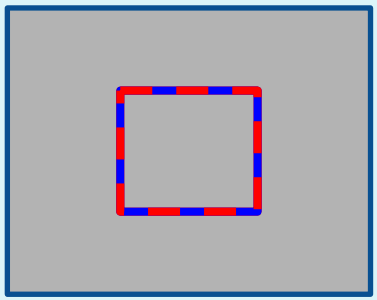
Eyes looking into distance

- Square comes closer





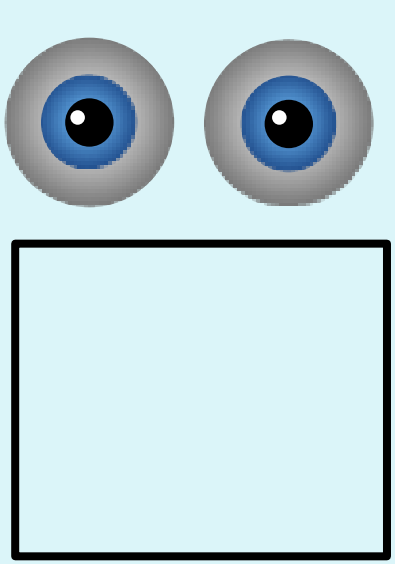
Retinal images

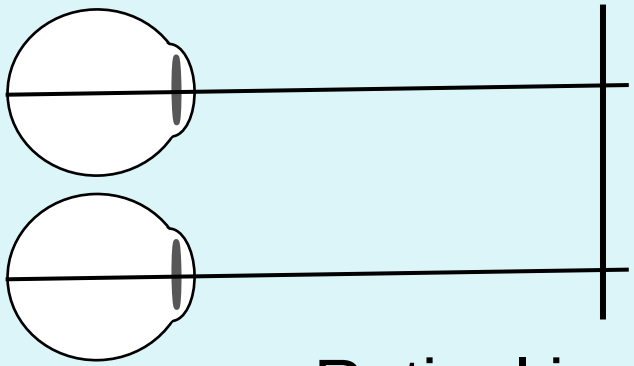


Horizontal disparity

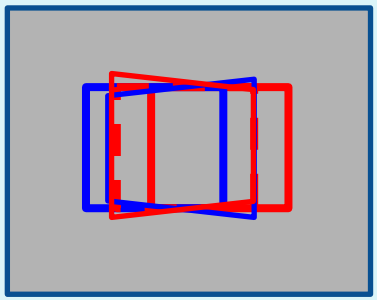
Eyes turned inwards

- Eyes converge on square so as to null retinal disparity.





Retinal images



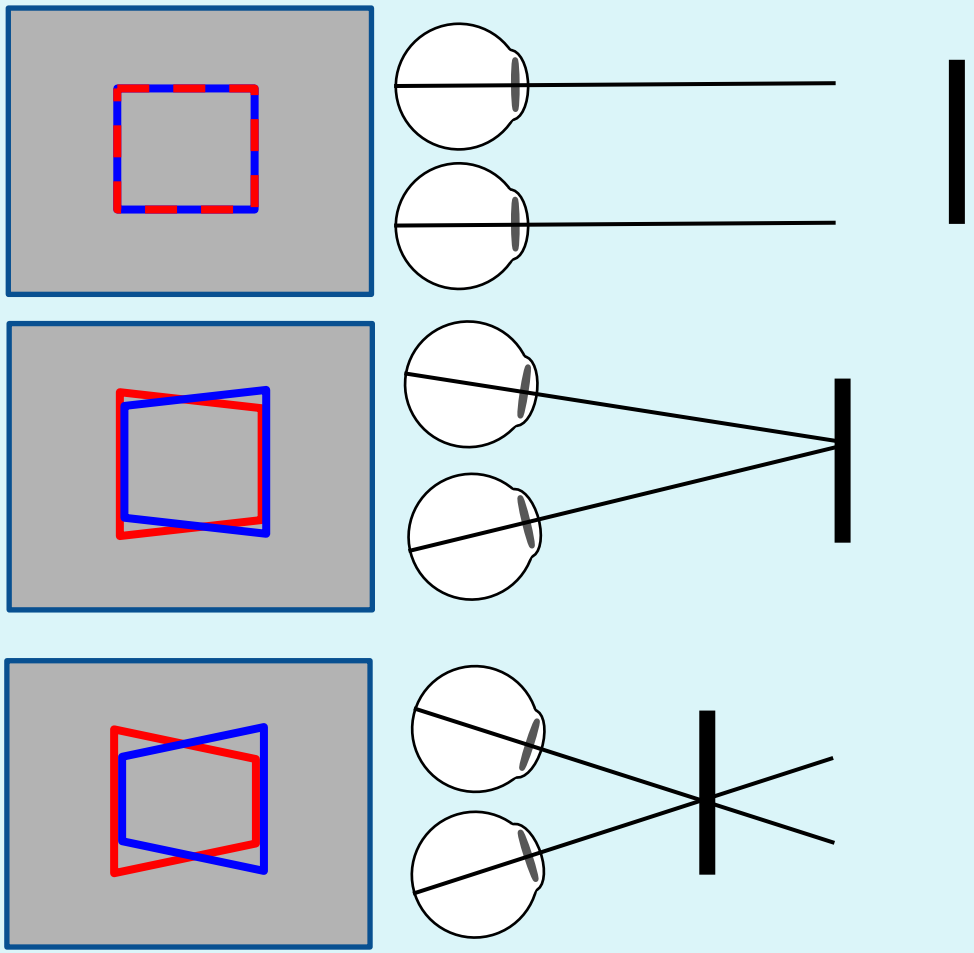
No horizontal disparity

Horizontal disparity

But vertical disparity

Viewing distance

- So, there are purely retinal cues to viewing distance.
- These can influence perception.

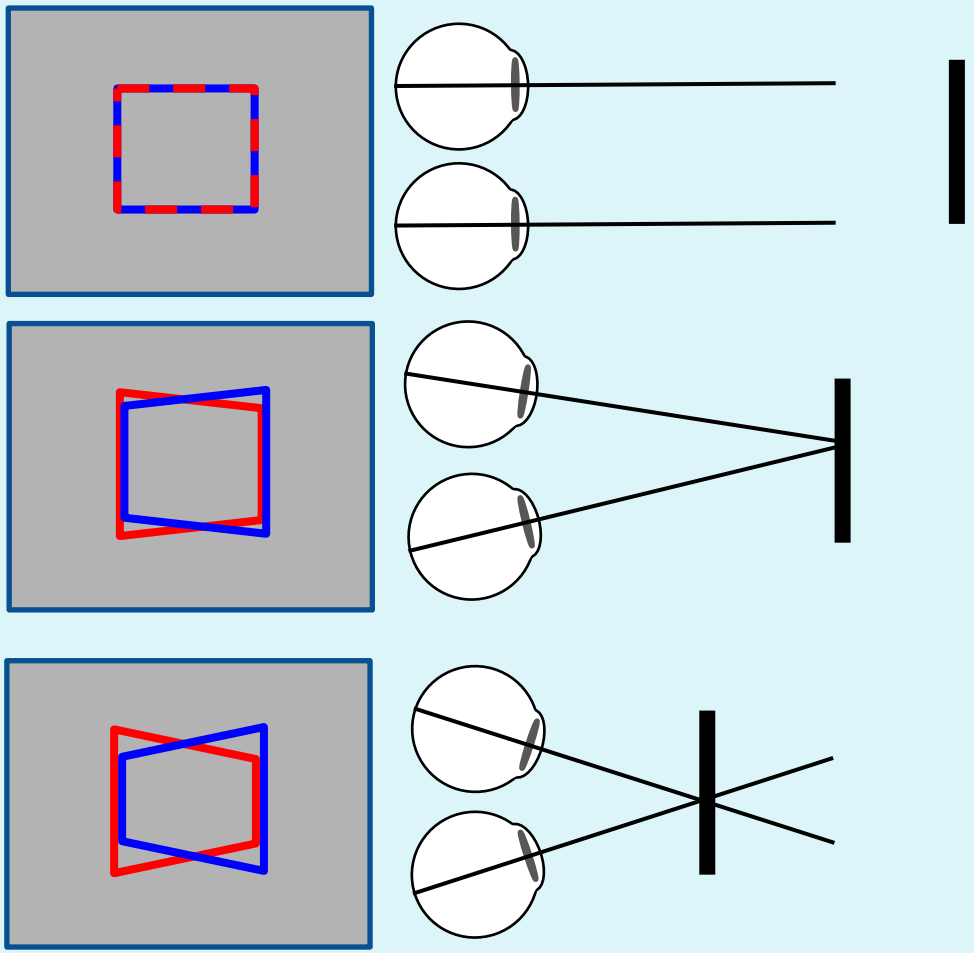


O’Kane L M, Hibbard P B, 2007, "Vertical disparity affects shape and size judgments across surfaces separated in depth"
Perception **36**(5) 696

“Observers adjusted the size and shape of a virtual, binocularly defined ellipsoid to match those of a real, hand-held tennis ball. The virtual ball was presented at three distances (20, 33, and 45 cm). Vertical disparities in a large surround surface were manipulated to be consistent with a distance of 16 cm or infinity. Both shape and size settings were influenced by this manipulation.”

Viewing distance

- So, there are purely retinal cues to viewing distance.
- These can influence perception.
- They are simulated by filming toe-in.

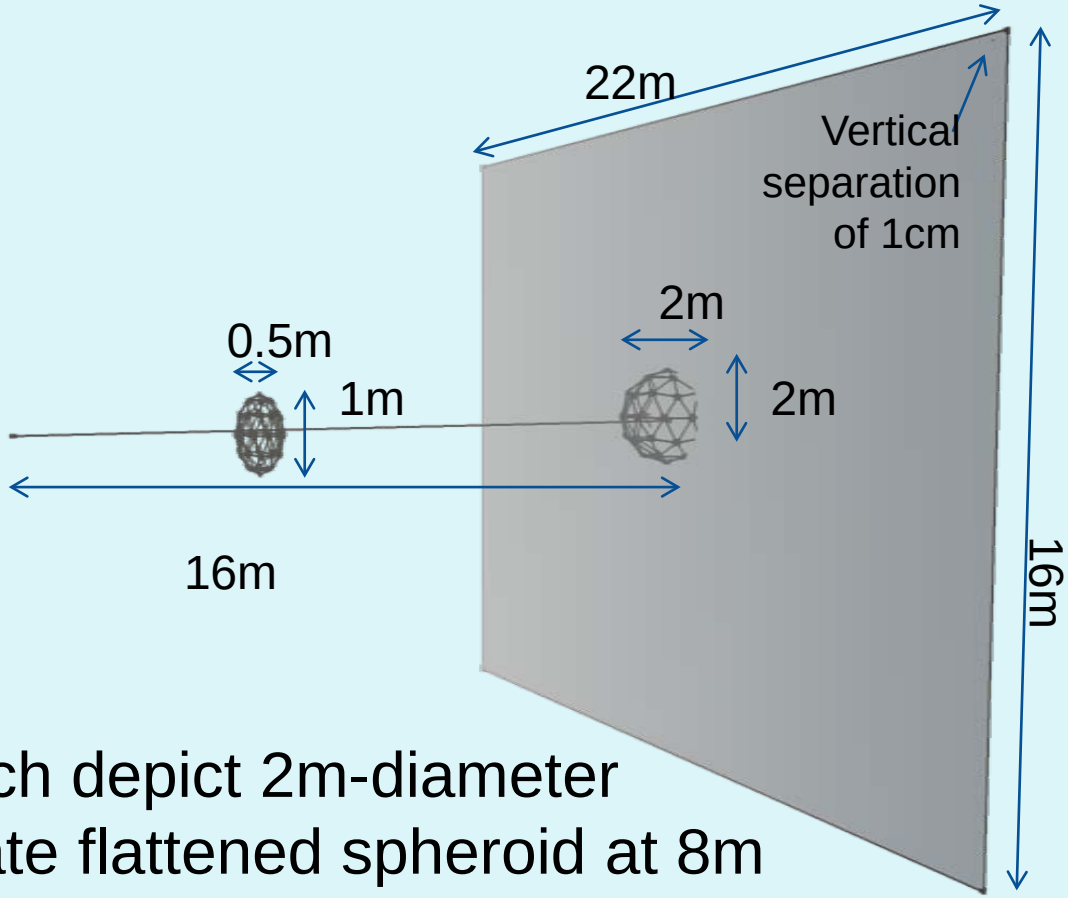


Example calculation

Viewing distance 16m, convergence angle just 14 arcmin (0.23deg).

"Toe-in" pattern of vertical disparity, with vertical on-screen separation of just 1cm at the corners.

This doubles the retinal estimate of convergence angle.

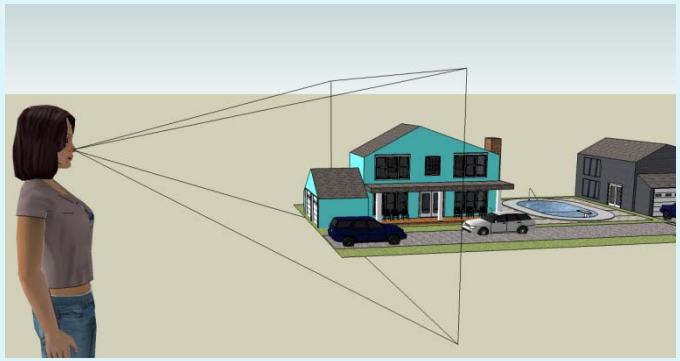


Horizontal disparities which depict 2m-diameter sphere at 16m now indicate flattened spheroid at 8m (diameter 1m in screen plane, 0.5m perpendicular).

Distortions in S3D

- Filming toe-in can lead to misestimates of viewing distance
- which may in turn lead to perceptual distortions, “cardboard cut-out” effect etc
- So should we not have vertical disparity on the screen?
  - i.e. don’t film toe-in, or correct in post

What are we trying to achieve in S3D?



- To reproduce reality (orthostereo / puppet theatre): make sure the screen is viewed frontoparallel and there is no vertical screen parallax.
- Simply to produce a good percept: there may be more flexibility.

4. Reconstructing depth: Implications for S3D

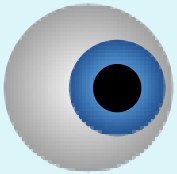
- Complex!
- Is influenced by brain's estimate of viewing distance
- which in turn is influenced not only by actual viewing distance
- but also by subtle aspects of the content
- including small keystoning due to toe-in.
- Not clear what the right answer is!

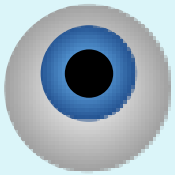
Take-home messages

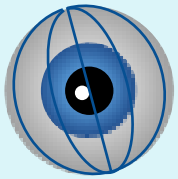
- Eye movements
  - Occur in response to your content and affect how it is seen
- Accommodation and convergence
  - May matter most for young
  - Are most comfortable at medium distance (so put content behind near screens and in front of far ones)
- Reconstructing depth from disparity
  - Depends on viewing distance
  - Can be distorted by subtle factors e.g. filming toe-in

More about eye movements

- Each eye has three degrees of freedom:
  - Azimuth (left/right)
  - Elevation (up/down)
  - Torsion (rotating around the line of sight)







What are we trying to achieve in S3D?

- A “puppet theatre”?