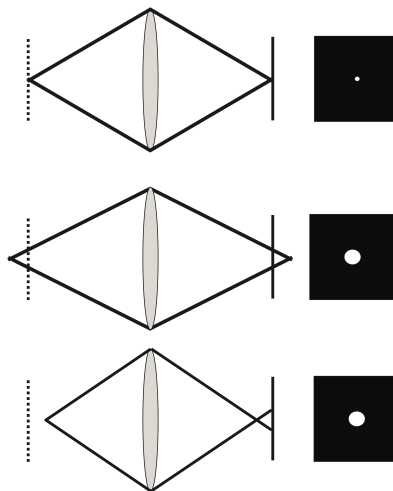# Depth of Field in 3D Stereoscopic Images

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Depth of Field in Photography

- Cameras have finite depth of field or depth of focus
  - Quantified by depth that elicits a given amount of blur
  - Typically perceptually defined
- DOF increases with f-number

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Depth of field as a tool


Depth of Field in Photography

- Shallow focus/selective focus to
  - Emphasize subject
  - Draw attention for close-ups
  - Change recognizability of background
  - Sense of scale or intimacy (more later)
- Rack focus
- Part of the "film look"

Accommodation

- Focus of the human eye
- Controlled by shape of the crystalline lens
- Acts to null blur at fixation in feedback loop
  - Can be driven by imperceptible blur
- DOF delimits region of imperceptible blur

Distant focus

Close focus

http://www.ssc.education.ed.ac.uk/courses/vi&multi/vmay08i.html
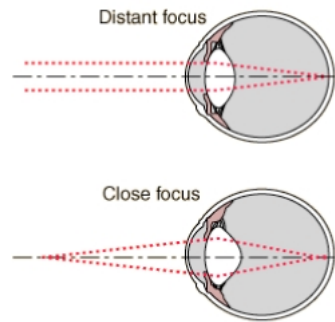
Accommodation and Depth of Field

- Does selective focus in films specify accommodation?
  - NO → accommodation for best focus is always at screen
  - Accommodation will not change with rack focus (or following)
  - DOF works if eyes follow cameras

Accommodation and Depth of Field

- Relation between accommodation and pictorial depth is broken
  - Result is "accommodation-depth conflict"
  - Blur varies with depth but …
  - Cannot be compensated with accommodation
- We will note similar conflict relationships between vergence and accommodation
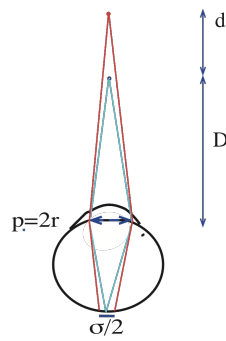
Blur as depth cue

- Static blur is ambiguous in sign and magnitude
  - Variations in sharpness of markings
  - Scaled by pupil diameter
- Can be disambiguated by
  - Changing accommodation (including fluctuation)
  - Aberrations
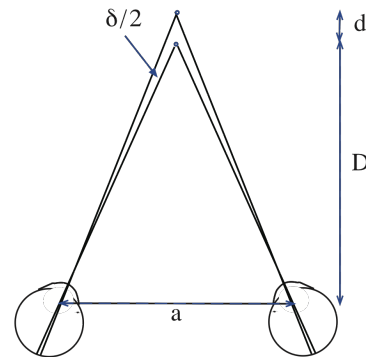 - Other cues; known sharpness
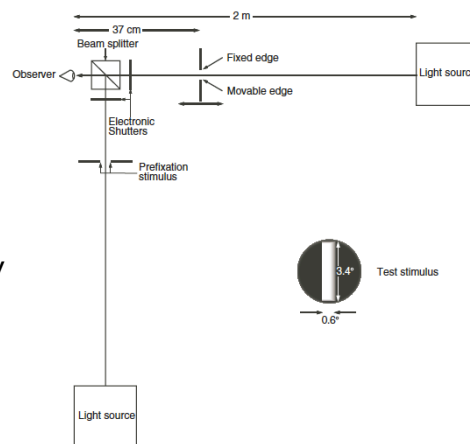
Nguyen, Howard, Allison, 2005

Disparity and Blur

Blur : $\tan\sigma \approx \dfrac{r|d|}{D^2}$

Disparity : $\tan\delta \approx \dfrac{ad}{D^2}$

Disparity and Blur

- Geometry is very similar for disparity, δ, and blur radius, σ. For viewing an object at depth d from fixation at distance D

$$\tan\sigma \approx \frac{r|d|}{D^2} \text{ compared to } \tan\delta \approx \frac{ad}{D^2}$$

Mather & Smith 2000

$$\tan\sigma \approx \left|\frac{r}{a}\tan\delta\right|$$

- Interocular separation, a, is typically much larger than pupil radius, r.
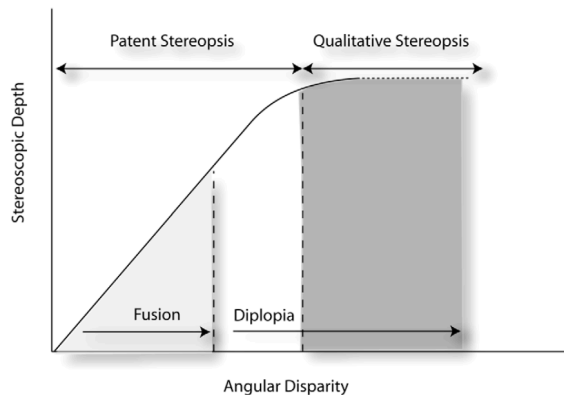
Disparity and Blur

- Stereopsis is more precise than depth from blur
  - We found mean DOF of 0.45D with short exposures
    - predicts depth thresholds from blur alone of at least 31cm at 1m
  - Active accommodation helps
    - e.g. DOF of 0.25D gives 20cm thresholds at 1m
  - Stereopsis gives mm precision at 1m

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Disparity and Blur

- However becomes effective around range where depths become too large for precise stereopsis

Disparity and Blur

- Large disparities associate with large blur
  - Stereoscopic range increases with increase in scale
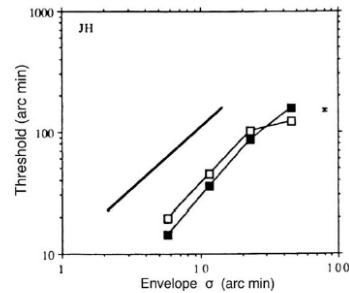- Textures disappear with significant blur taking disparity signals with them (useful in film)

Fig. 7. The upper disparity limits for Gabor stimuli, as a function of envelope size, reproduced from Wilcox and Hess (1995). The open and closed symbols represent spatial frequencies of 0.66 and 1.31 c/deg, and the solid line without symbols indicates a slope of 1 on log-log axes. Over a large range of envelope sizes (σ = 5.73–45.8 min) upper disparity limit was not affected by carrier frequency.

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Disparity and Blur

- In S3D display, blur and accommodation cues consistent with flat display
  - Camera DOF does not provide dynamic DOF cues
  - Linked to reduction in percepts of depth
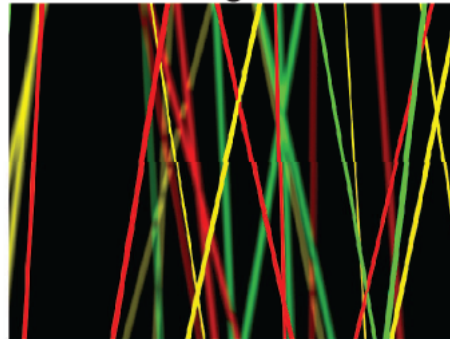 - Fatigue, fusion issues
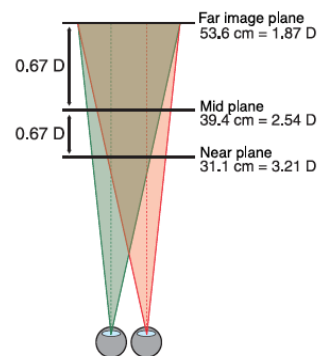
Schematic of multifocal display used by Banks and colleagues

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Blur as depth cue

- Adding appropriate focus cues to a stereo display enhances stereopsis:
  - Depth judgements
  - Aids in interpretation of disparity: matching, occlusions, fusion
  - Improves reports of visual comfort

Hoffman, Girshick, Akeley, & Banks 2008

Blur as depth cue

- Caveats
  - Defocus blur aids stereopsis but this is not necessarily true for shallow focus
  - Effects are for **near viewing** (mobile, games)
  - Movie theatre viewing is beyond the effective natural range of blur as a depth cue
    - Example: Accommodate at 2m with 0.5D depth of field, depths from targets at distances of 1m to infinity are within depth of field
    - Also true for much television viewing
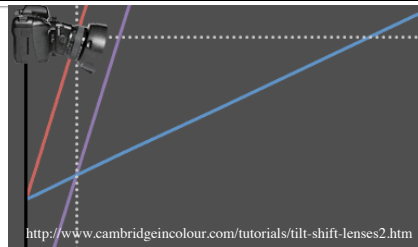
Depth of Field and Sense of Scale

- Why is depth of field effective in movies?
  - Suggests exaggerated depth
  - Blur due to depth of field is normally only experienced with near viewing
  - Conversely, shallow depth of field suggests near viewing
  - Fusion of large disparities

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Depth of Field and Sense of Scale

- Tilt of lens with respect to imaging plane
  - Changes orientation of plane of focus (Scheimpflug principle)
  - Allows focus on surfaces extending in depth
  - Tilt-shift photography and miniatures

http://www.cambridgeincolour.com/tutorials/tilt-shift-lenses2.htm

http://www.northlight-images.co.uk

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http://www.smashingmagazine.com

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Depth of Field and Sense of Scale

- Unexpectedly shallow depth of field suggests near viewing
  - To be consistent objects should be perceived as miniature
  - Recent data from Held et al (2010) confirms the subjective experience
- This type of scaling may contribute to sense of intimacy with shallow focus

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Accommodation-Vergence Mismatch in Stereo Displays

- Viewer should
  - Converge to look at disparate targets but
  - Accommodate on screen
- Conflict for **near** viewing
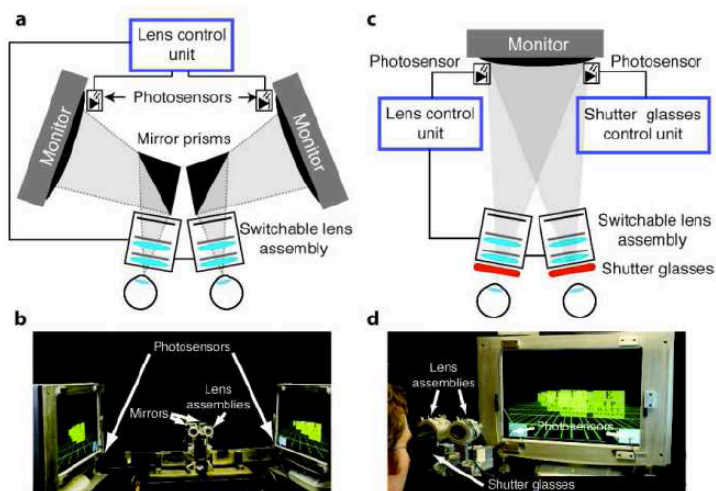- No conflict for imagery at screen distance

Pace Fusion 3D, Photo Credit CNET

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Displays that Support Blur Cues

UC Berkeley

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Displays that Support Blur Cues

Actuality Perspecta

Lack of blur cues and the ergonomics of 3d film

- Many artefacts in current 3D displays
  - Distortions, flicker, alignment, mismatch, ghosting, colour, …
  - Likely contribute to 'simulator sickness' symptoms
- What if we present present artefact-free disparity but no natural depth of field cues?
  - Blur and accommodation conflict
  - Vergence and accommodation conflict

Lack of blur cues and the ergonomics of 3d film

- Cue conflict seems to put strain on visual system
  - Discomfort, Eye Strain, Fatigue
  - Weakens depth effects, reduces fusion ability
- Stereopsis makes 3D experience more compelling
  - May promote other simulator sickness contributors increasing symptoms

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Lack of blur cues and the ergonomics of 3d film

- Vergence-accomodation conflict is a factor for **near to eye** displays
  - Content delivery on mobile devices
  - Essential physiological links
  - Can learn to dissociate; Adaptation to VR displays in as little as 10 minutes (Mon-Williams)
  - Recovery is usually rapid and similar to adaptation
  - No large scale studies (effects on susceptible people with borderline oculomotor function)

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Summary

- For film, shallow focus does not simulate natural dynamic depth of field but is a rather a useful cinematic construct that needs to be re-examined for S3D

Thank You!