# SMPTE 2nd Annual
## International Conference on Stereoscopic 3D for Media and Entertainment

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# WELCOME!

# Depth Cue Interactions in Stereoscopic 3D Media

Robert Allison, York University

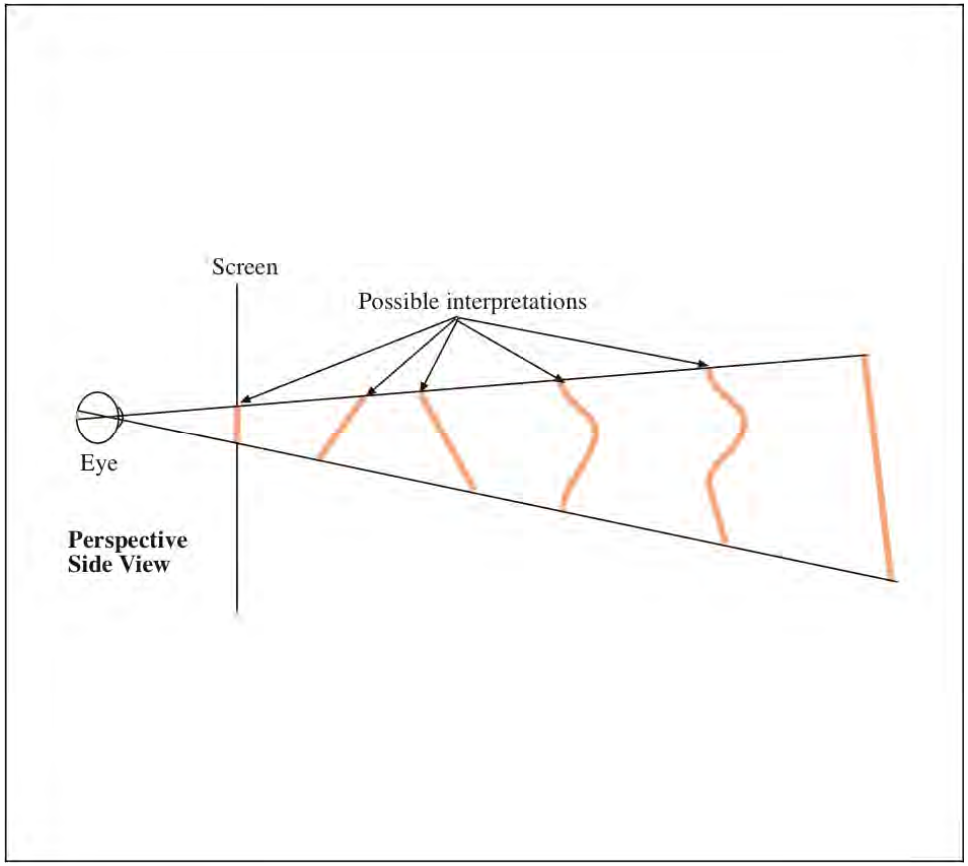
# Depiction of Depth and Space in S3D

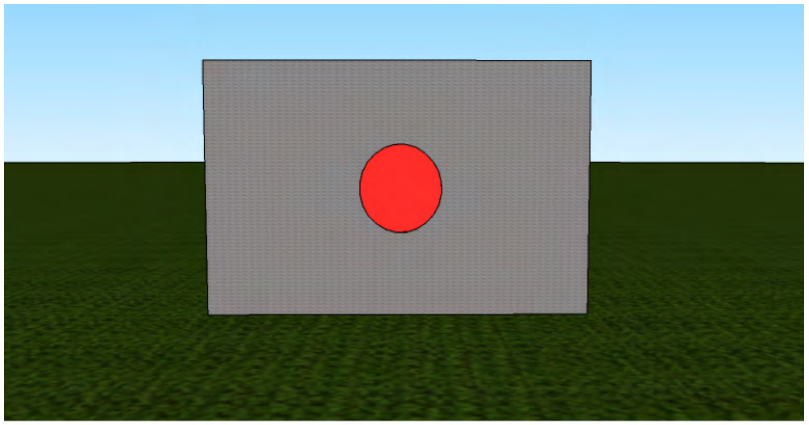
- Vivid sense of depth and solidity from binocular disparity
- Traditional 'pictorial' cues present and active
  - Shading, shadows, defocus blur, aerial perspective (haze, smoke), linear perspective, texture gradient, occlusion, motion
  - Not subsidiary or secondary cues

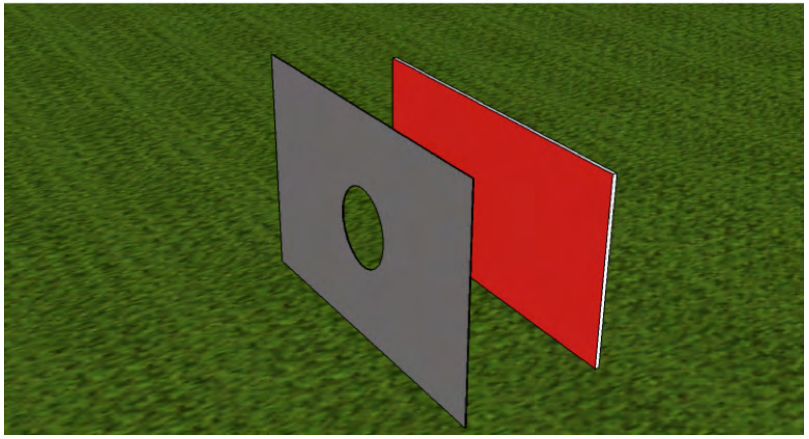
Raphael, School of Athens 1510

# Essential Ambiguity of Vision

- Depth cues provide incomplete, imprecise, ambiguous, and even contradictory depth information
- Vision as inverse graphics (or photography)
  - 'Invert' the imaging process and recover the 3D world
  - Image is compatible with multiple possible realities
    - Including a 2D image on a painting, screen or television

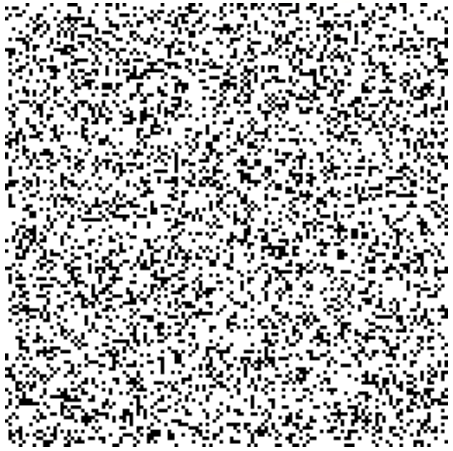

Screen
Possible interpretations
Eye
Perspective
Side View

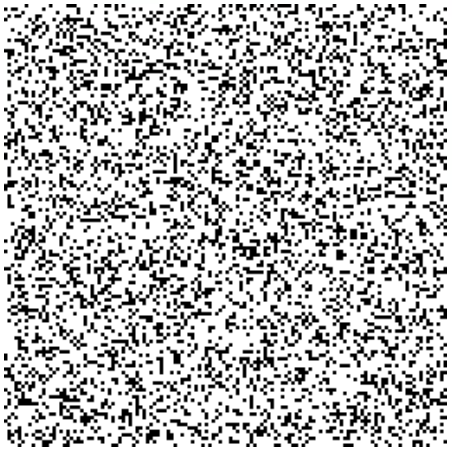




# Ambiguity in stereopsis

1. Correspondence problem





2. A given disparity can correspond to a range of possible depths
   - Vergence or vertical disparity is limited to close range and has limited accuracy

# Interactions of Disparity and Other Cues

- Binocular and monocular vary in the depth judgments that they support and their reliability
  - Discriminating a difference in depth
  - Ordering objects in depth
  - Judging slant or curvature
  - Shape and relief
  - Judging speed or direction of motion in depth
  - Surface properties
  - Accurate measures of depth between objects

# Cue Combination in S3D

- In S3D film and other content
  - Perceptions are complex and multifaceted.
  - Cue integration and combination needs to be considered on all these levels
  - Occur simultaneously and often seamlessly

# How to Resolve these Ambiguities

- Not all possible interpretations are equally likely
  - Constraints: Structure and regularities of the world
  - Consistency among cues
- Choose the most likely 3D dimensional world
  - 'Unconscious inference' for Helmholtz
  - Probabilistic interpretation of sensory signals

# Cue Integration

- Monocular cues vary in the degree that they support specific judgments
  - For example, occlusion is one of the least ambiguous depth cues tells you nothing of the amount of depth
    - How to combine with stereopsis for depth magnitude?
    - Two cues are not commensurate
- Cue combination must account for precision, reliability and range
- Tolerant of bias

# Cue Conflict

- When two or more cues provide different and incompatible information
  - Within binocular cues (e.g., vergence, stereopsis)
  - Between stereopsis and other cues
- S3D media almost *always produce cue conflict*
  - Essential conflict due to technology; vergence and accommodation
  - Nature of the medium; e.g., choice of lens or display size
  - 'Natural' conflict; e.g. unusual lighting direction

# Models of Cue Combination

1. Cue dominance or veto
2. Summation and averaging
3. Disambiguation
4. Calibration and adaptation
5. Dissociation

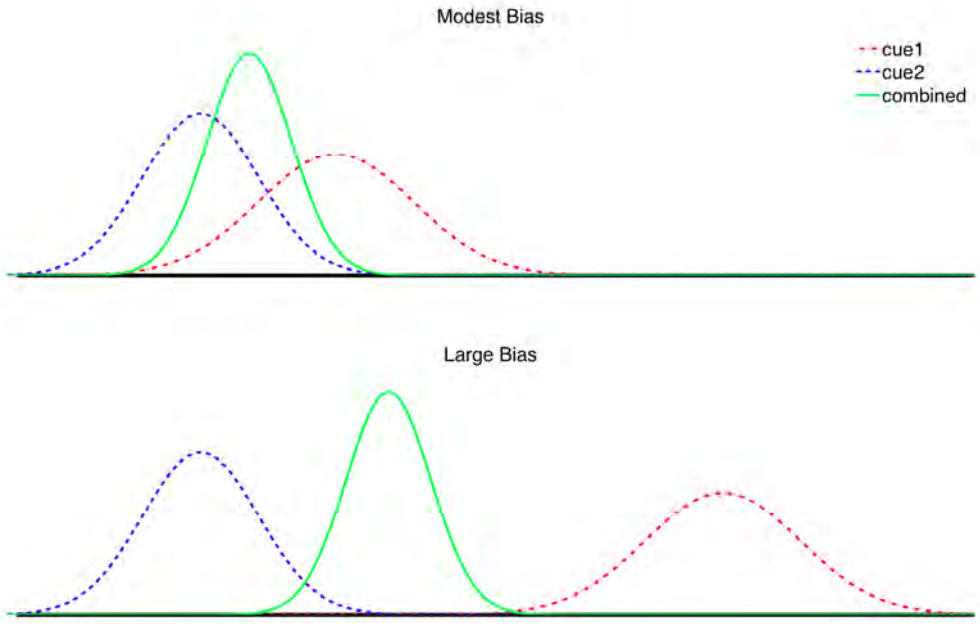
# Models of Cue Combination

- Maximum likelihood estimators (MLE) and Bayesian estimators have proven successful
  - Likelihood of various scenes and perceptions
  - Reliability of cues (effects of distance, slant …)
  - Dependencies among cues
  - Robustness when they disagree

$$D_{optimal} = w_1 \cdot D_{cue1} + w_2 \cdot D_{cue2}$$

$$w_1 = \frac{\frac{1}{\sigma^2_{cue1}}}{\frac{1}{\sigma^2_{cue1}} + \frac{1}{\sigma^2_{cue2}}} \quad \text{and} \quad w_2 = \frac{\frac{1}{\sigma^2_{cue2}}}{\frac{1}{\sigma^2_{cue1}} + \frac{1}{\sigma^2_{cue2}}}$$

$$\frac{1}{\sigma^2_{optimal}} = \frac{1}{\sigma^2_{cue1}} + \frac{1}{\sigma^2_{cue2}}$$



# Cue Conflict for Depth Sign

- Conflict in depth order (in front versus behind) often considered especially strong conflicts
- Depth sign errors in automated 2D-3D conversion
- Pseudostereo

# Cue Conflict for Depth Sign

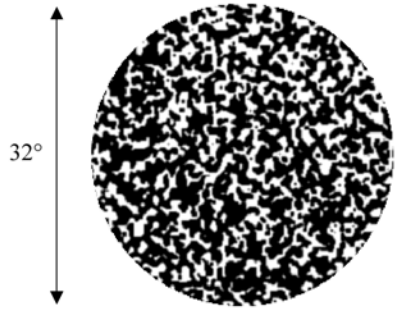
- Window violation
  - Occlusion cues indicate the frame edge is in front of imagery that is stereoscopically in front
  - Cue dominance as occlusion cue ‘pins’ the surface to the edge of the screen
  - In other cases strange and uncomfortable cue dissociations can be perceived

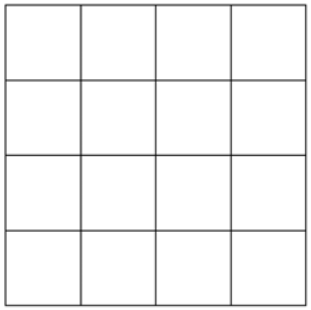
# Cue Conflict for Depth Magnitude

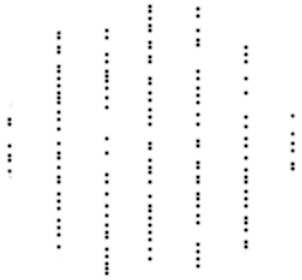
- Cues such as perspective and shading act to modulate the depth from disparity
  - Differential effects of rig and projection parameters (such as focal length, IA, depth of field, screen distance, and screen size)
  - Impact other aspects besides depth such as apparent size

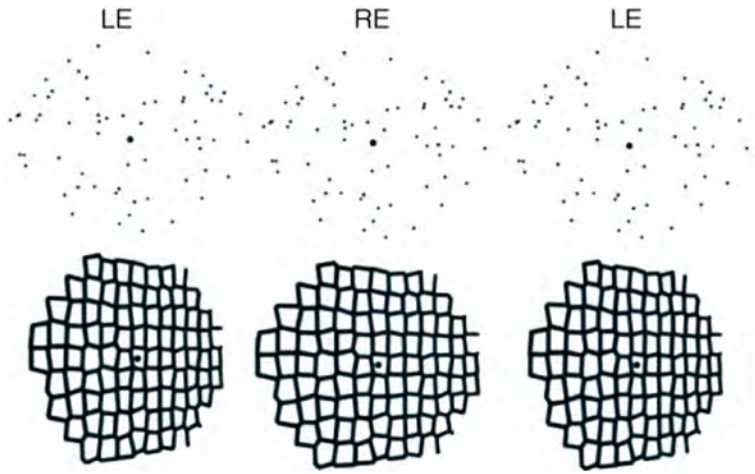
# Cue Conflict for Slant

- The orientation of surfaces in depth, or slant, is important for shape and object recognition
- Slant is produced by perspective cues (e.g. texture gradients) and disparity
  - Relationship varies with
    - Focal length and magnification on the one hand and rig parameters such as IA on the other
    - Viewing geometry



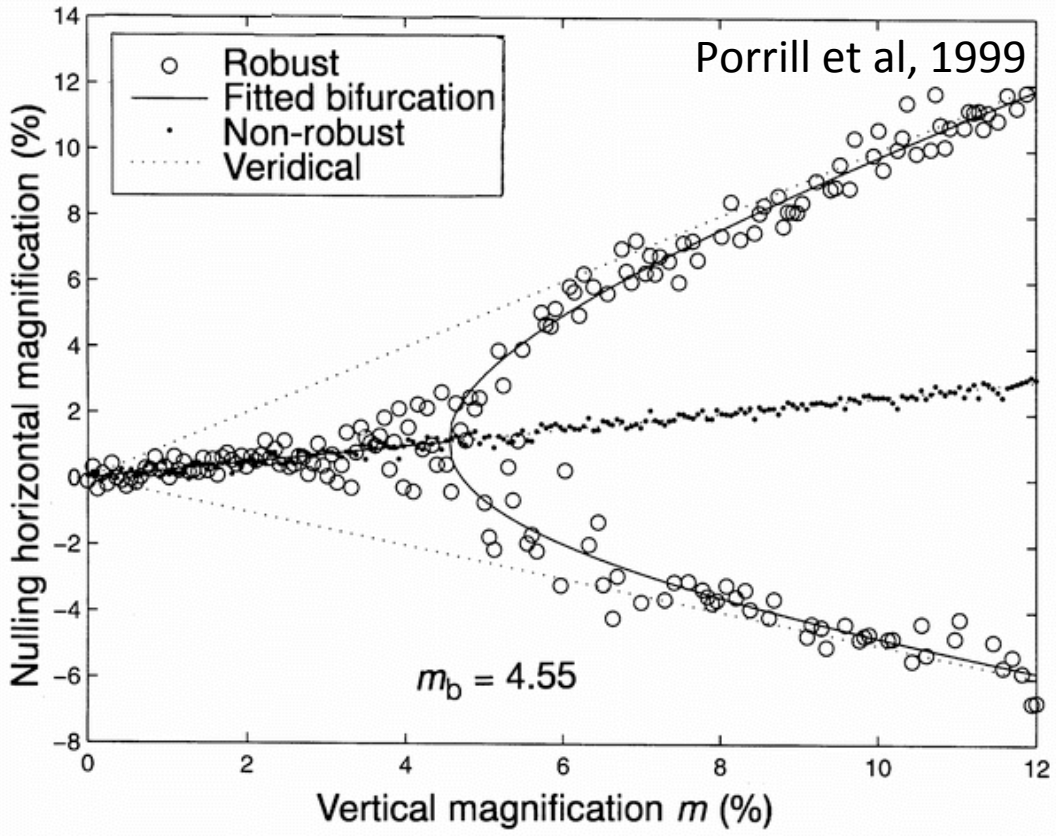





**Hillis J M et al. J Vis 2004;4:1**

Allison, R.S. et al, Vision Research, 2000

- Weight perspective and disparity to arrive an estimate of surface slant
- Both studies found robust behaviour
- Observers 'chose' perspective or disparity
  - Idiosyncratic
  - Not always optimal



# Cue Conflict for Appearance

- Stereo is effective for transparency, surface perception and atmospherics
- Interaction of stereopsis with shading and lighting in an S3D context
  - Lighting for depth can enhance the sense of volume and space

# Cue Conflict for Appearance

- Should specular highlights be avoided at all costs?
  - Binocular differences in intensity produce percepts of luster that supports the perception of surface gloss
  - Polarization sensitive beamsplitter in a mirror rig
  - Specularities are highly directional phenomenon. We might be more sensitive cue conflict here

# Summary - Cue Trading

- Cue combination and conflict is essential and unavoidable in S3D
- Reduce disparity while ‘turning up’ the perspective, motion parallax or shading (Ware, Siegel, …)?
- Possible, even mandatory if viewer has access to only the final perception
- But …

# Summary - Cue Trading

- On the other hand there are limits to the degree this can be accomplished and automated:
  - Robust estimation should discount biased cues (i.e. veto)
  - Weights adopted vary by viewer, even with good stereopsis
  - Weights vary with task, experience, scene, and location
- Thus cue trading is a complex scene-dependent and often idiosyncratic process

# The End

**Thanks to: L. Wilcox, K. Benzeroual, Ali Kazimi and the 3DFlic team**