Why Pictures Look Right when Viewed from the Wrong Place

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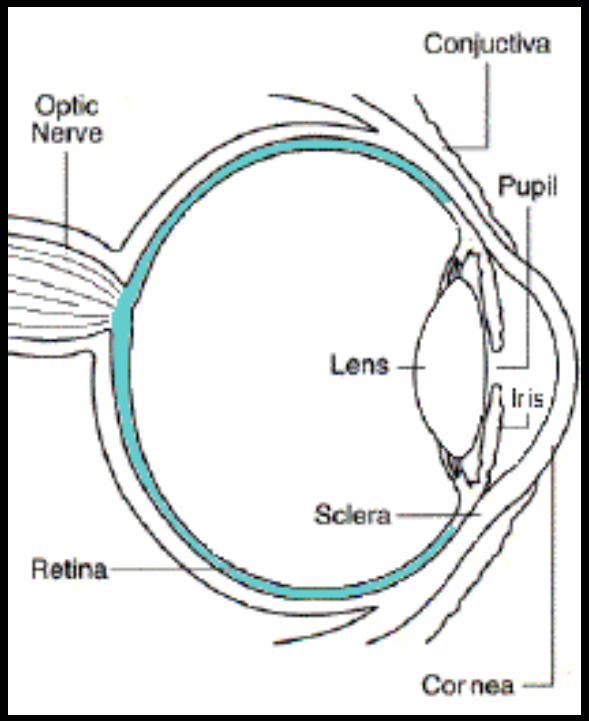
What's a picture?

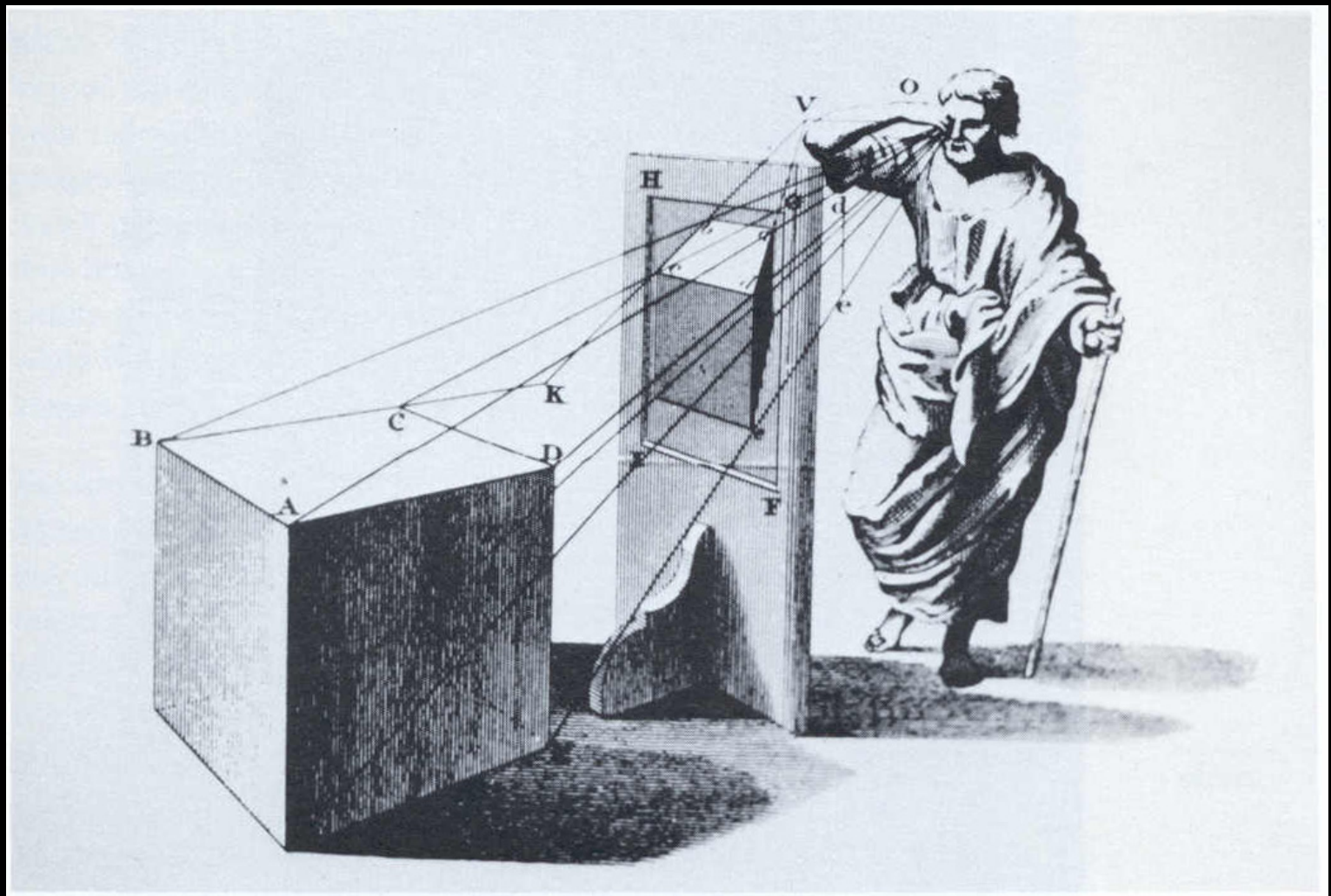
- 2D surface using perspective to portray 3D scene
- Paintings, photographs, movies, television, digital displays, virtual reality
- Of interest to artists, neuroscientists, computer scientists for centuries

Retina

- Eye has retinal “projection screen” at back
- *Retinal strategy*: interpretation of the world directly from image on retina (without further processing by the brain)



Center of Projection (*CoP*)

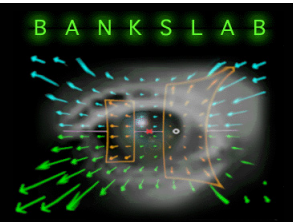


The visual cone, from B. Taylor, *New Principles of Linear Perspective* (1715).

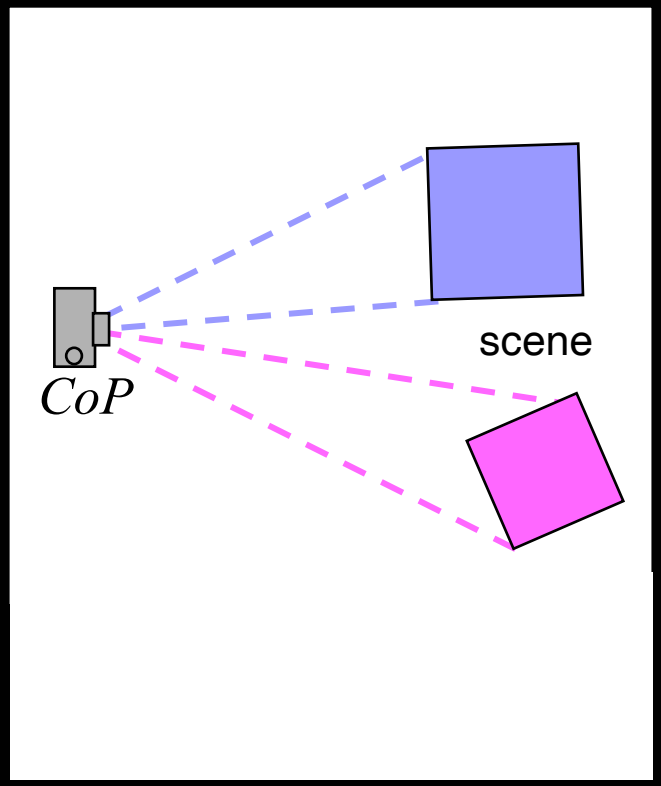
Normal picture viewing

- Pictures rarely viewed from the “right place” (CoP)
- *Retinal image* changes depending on viewing position
- Viewers rarely aware of projected distortions
- Brain is *invariant* to viewing position (suggesting retinal strategy is not used)

Projections of scenes & of pictures of scenes



plan view



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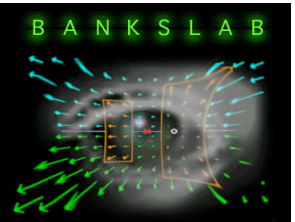
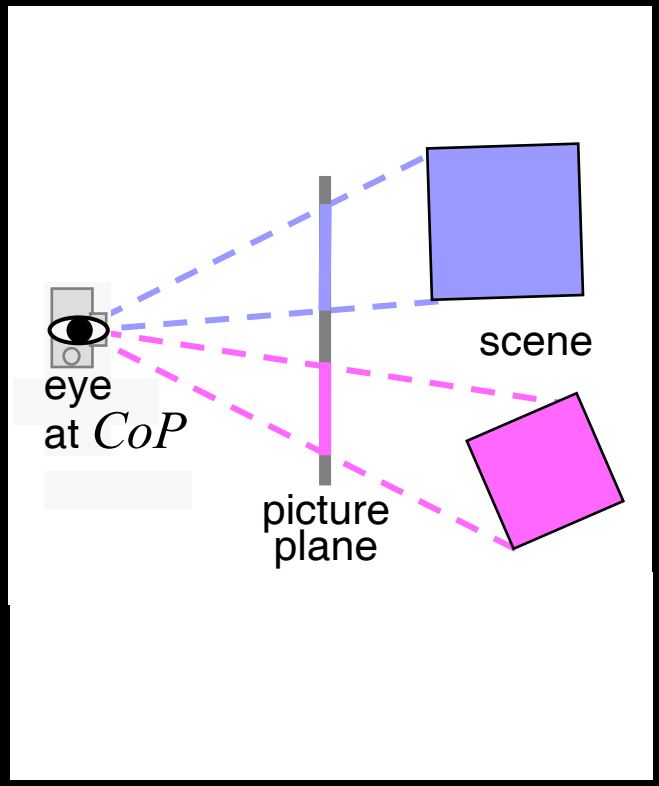
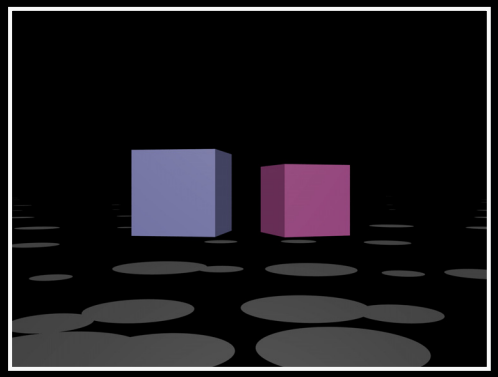


plan view



eye at CoP

retinal image of picture



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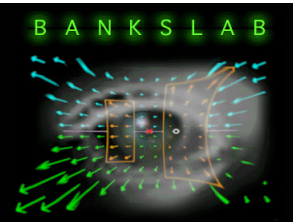
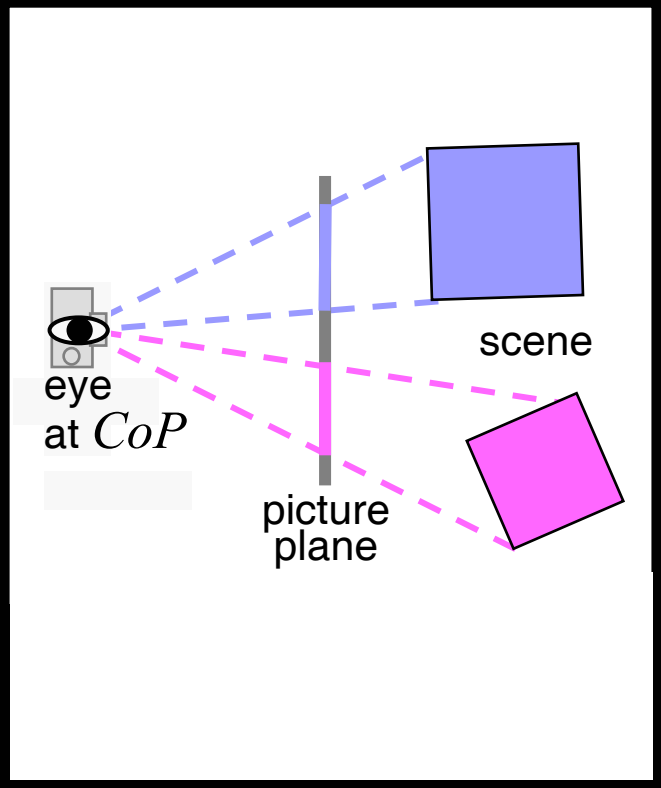
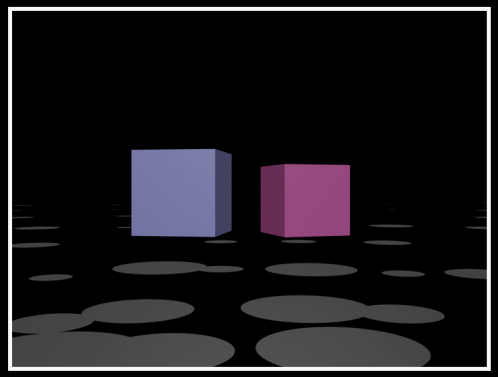


plan view

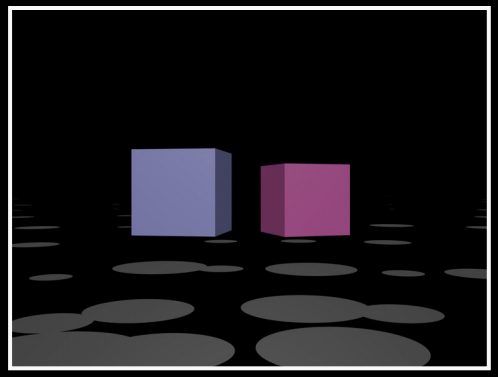


eye at CoP

retinal image of picture



retinal image of scene



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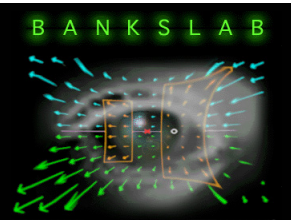
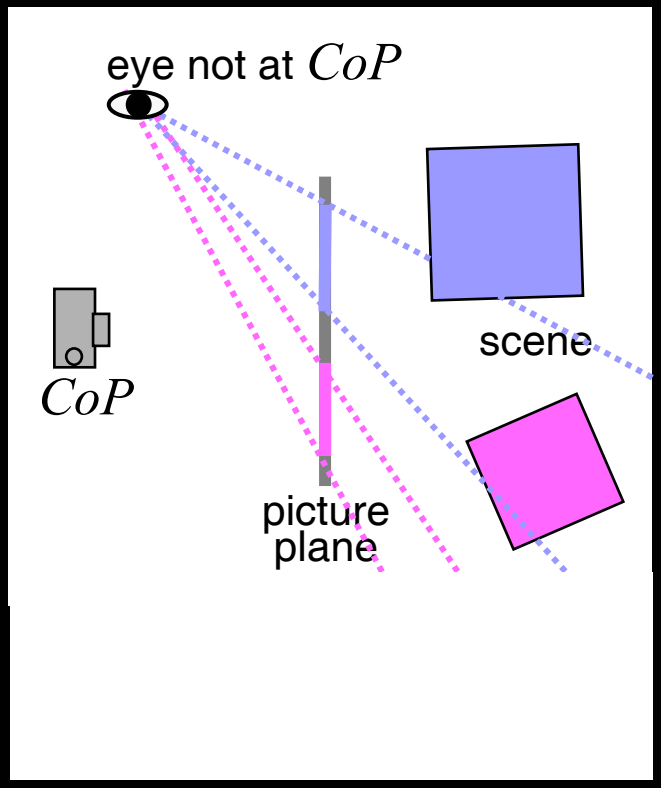


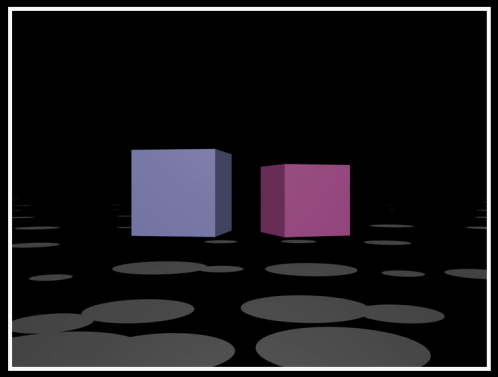
plan view

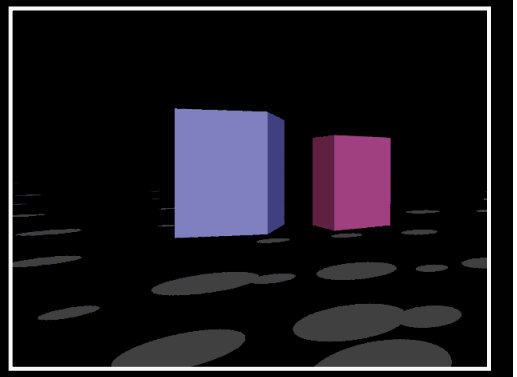


eye at *CoP*

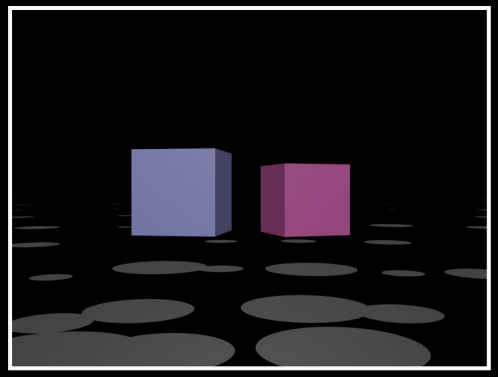
eye not at *CoP*

retinal image of picture





retinal image of scene



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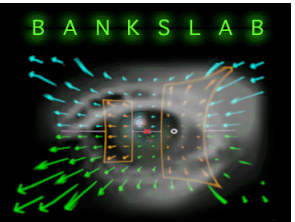
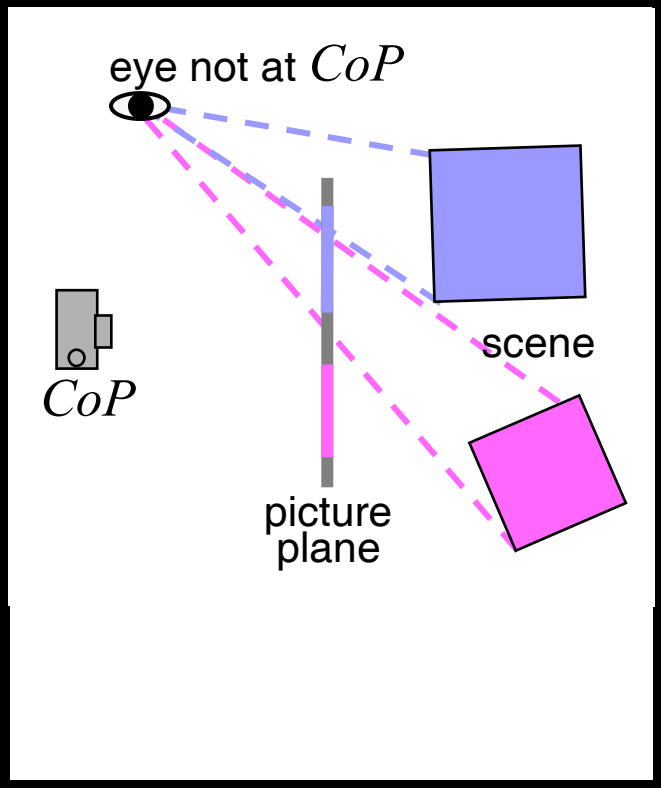


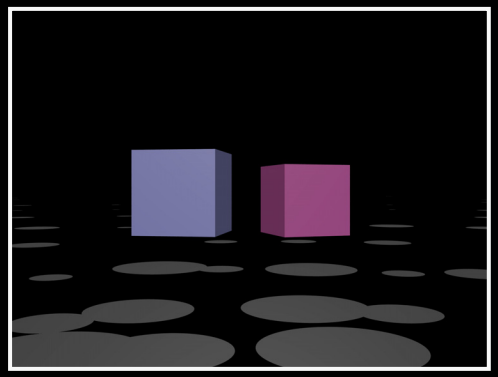
plan view

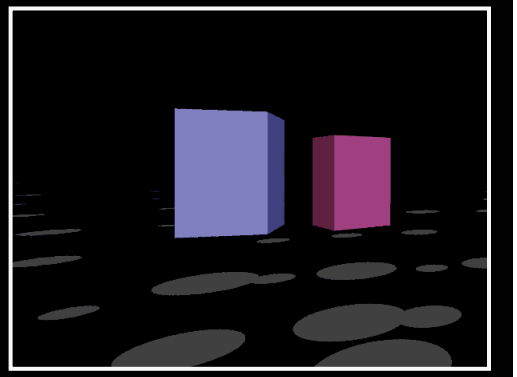


eye at *CoP*

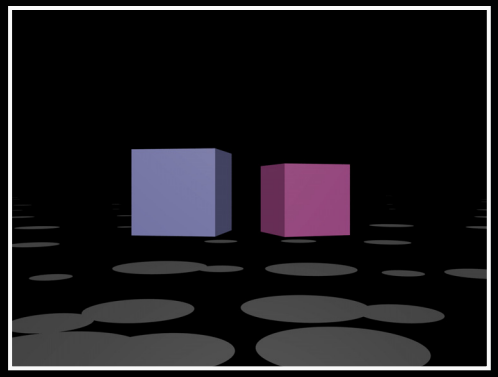
eye not at *CoP*

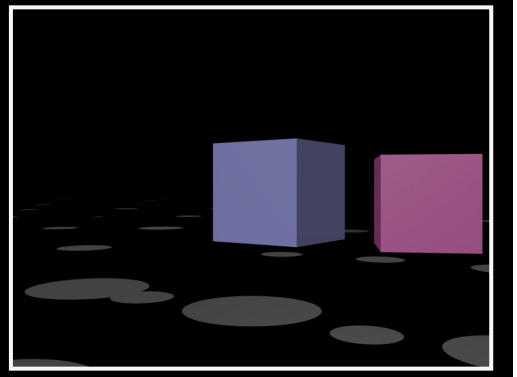
retinal image of picture



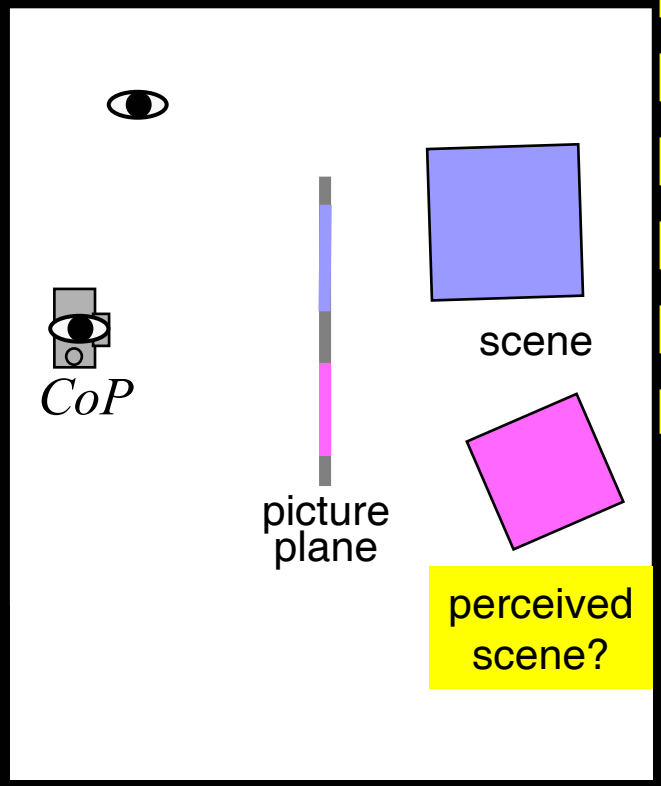


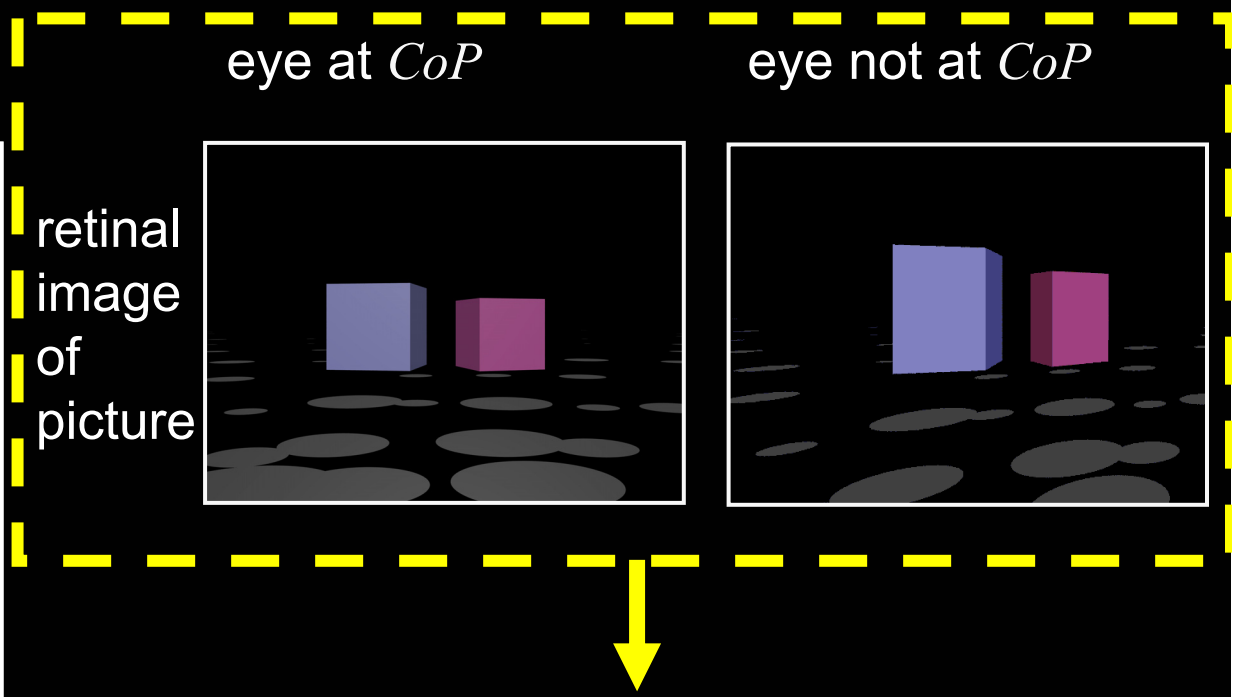
retinal image of scene





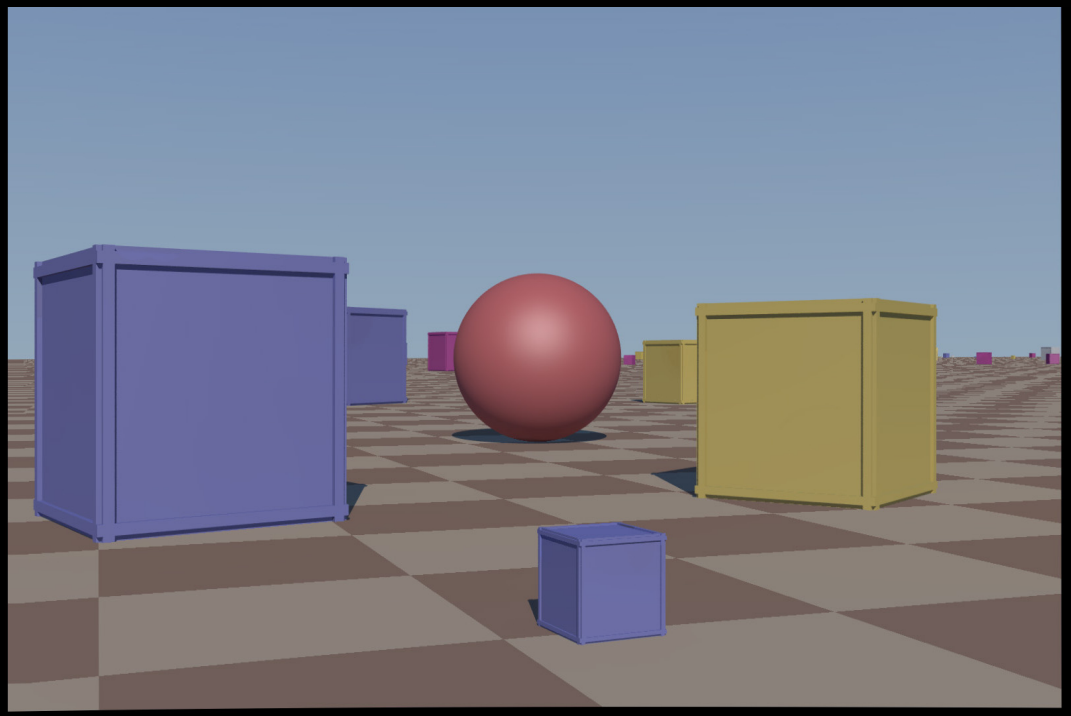
Projections of scenes & of pictures of scenes

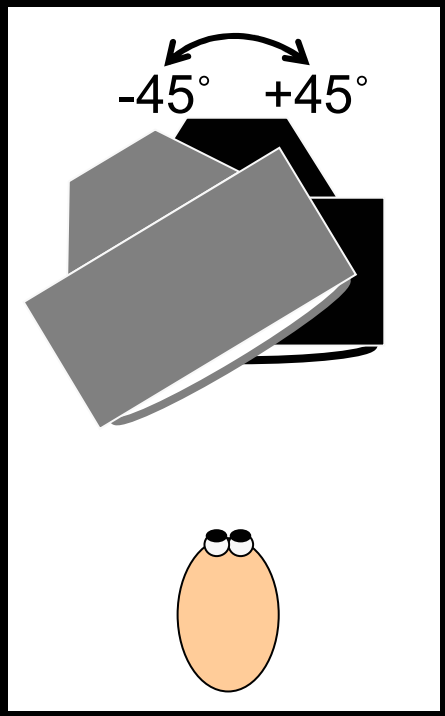




similar perceived scenes

3 Experiments

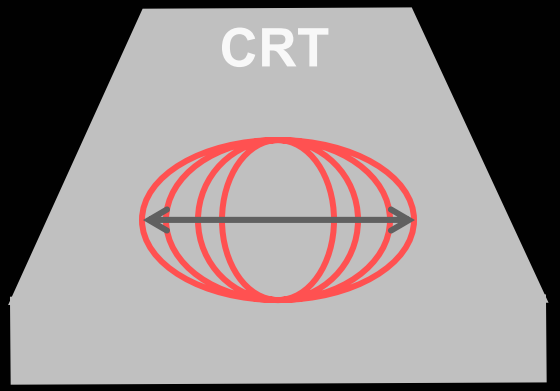




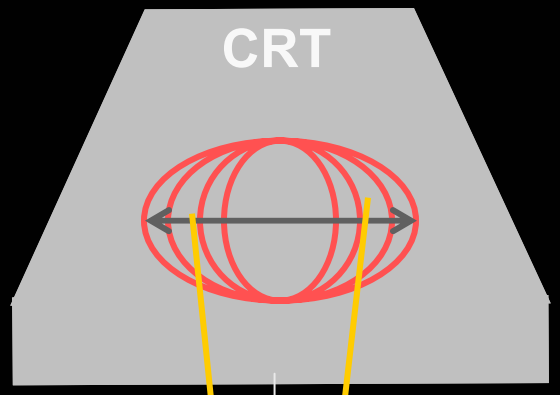
spatially calibrated

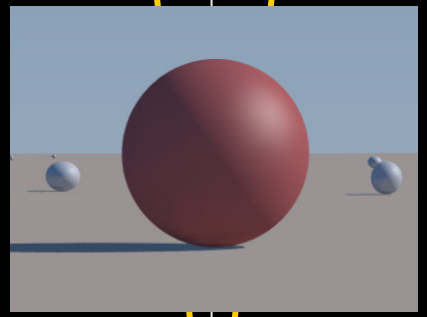
bite bar

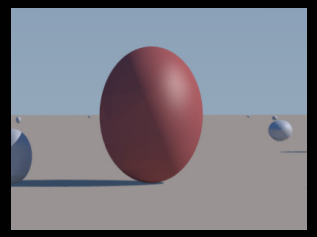
Observer's task: adjust aspect ratio of ovoid until it appears spherical

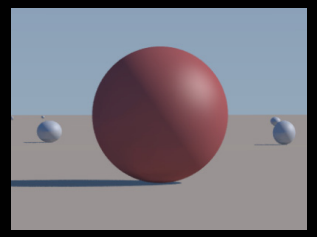


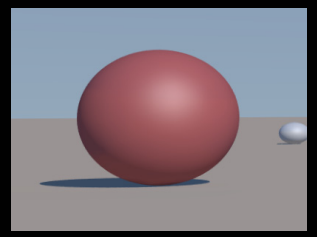
Expt 1: How invariant are we to viewing position?

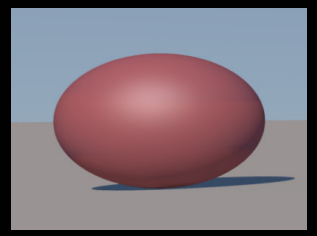










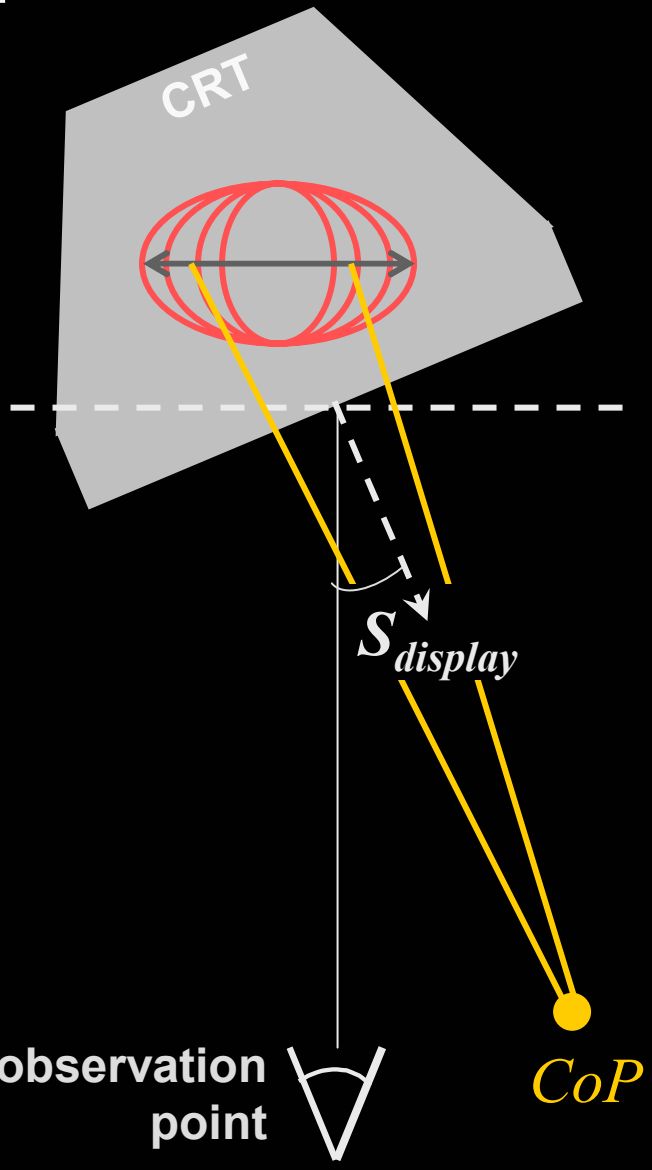


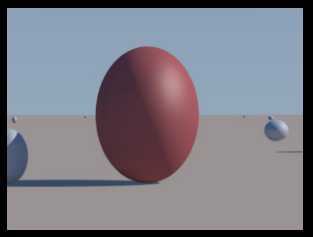
observation point

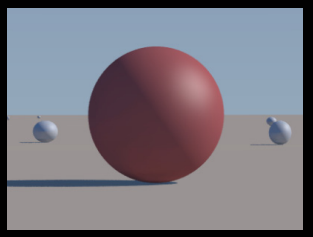
CoP

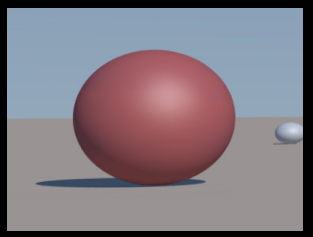
Expt 1: How invariant are we to viewing position?

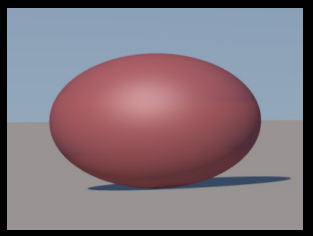
Varied viewing angle $S_{display}$ to measure invariance at oblique viewing positions



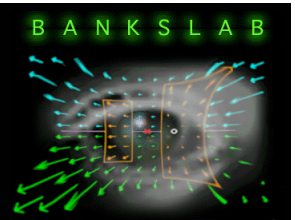








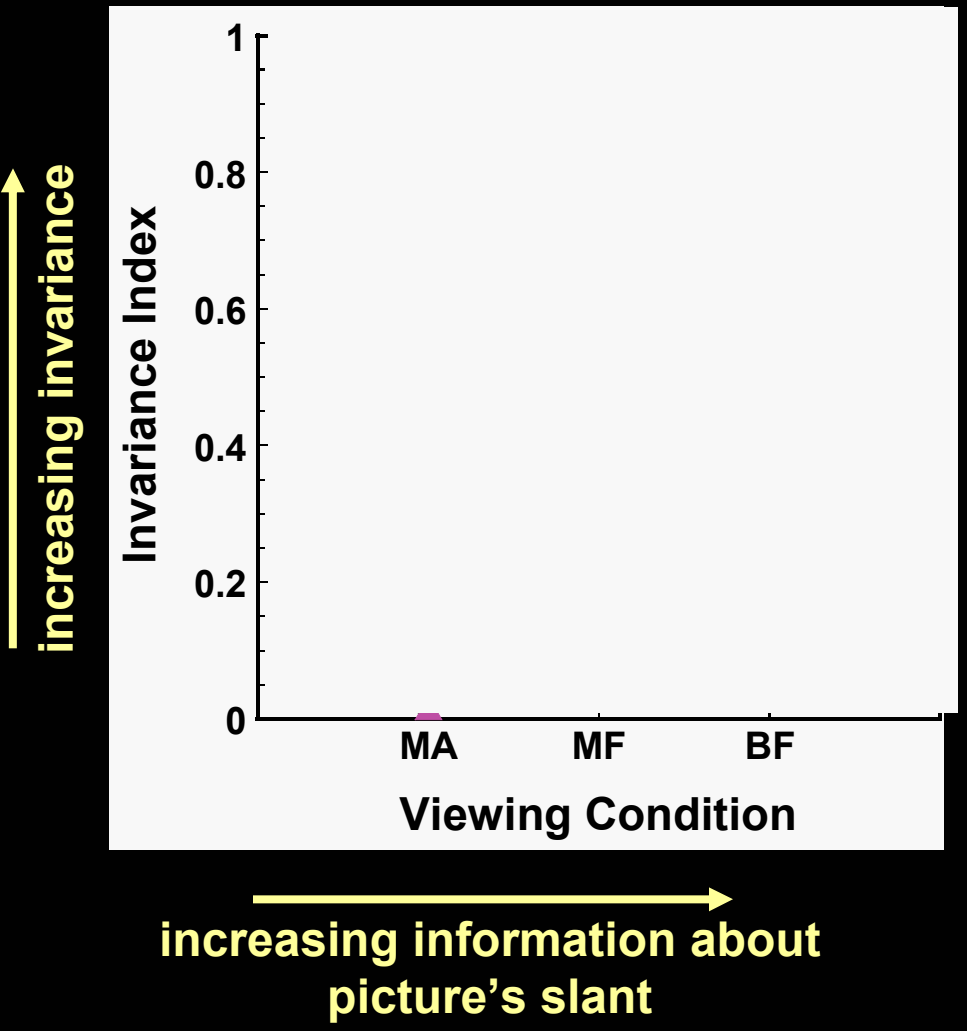
Varying information for picture's slant



increasing picture's slant information

- No picture slant info:
  - monocular through aperture (no frame info), dark room (MA)
- Minimal picture slant info:
  - monocular without aperture (frame), dimly lit room (MF)
- Rich picture slant info:
  - binocular without aperture (frame), dimly lit room (BF)

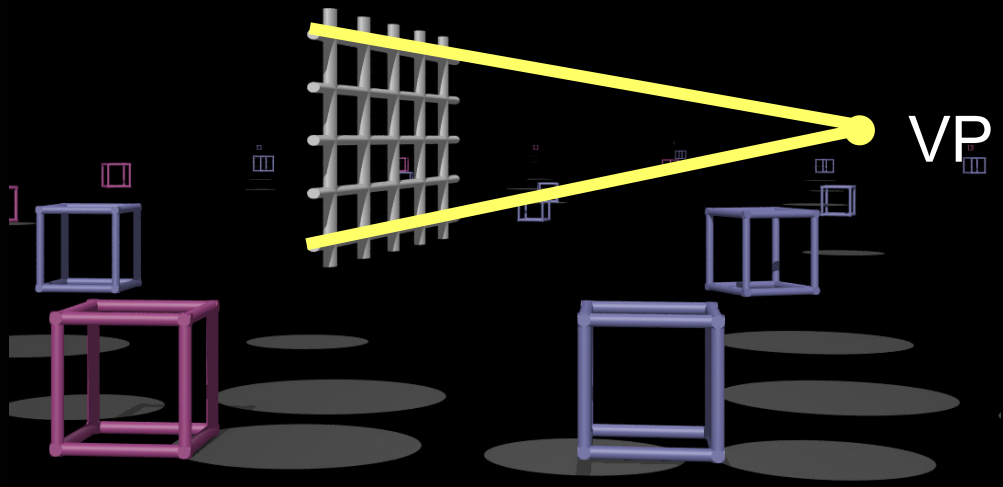
Expt 1: summary data



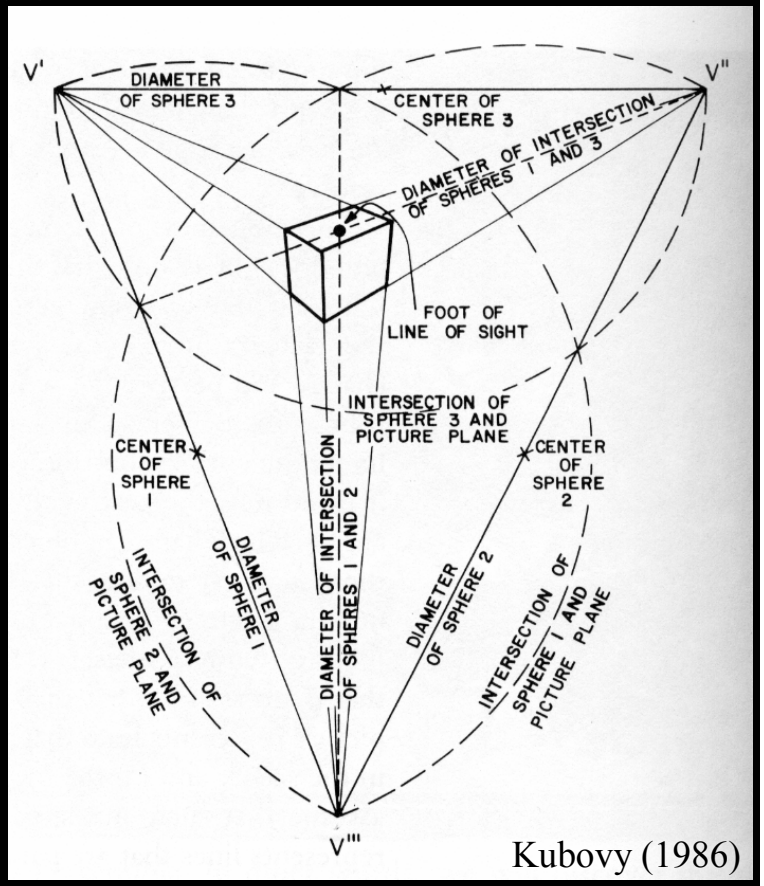
- Evidence for invariance when information to picture's slant is available (BF)
- Little evidence for invariance (retinal strategy) without picture slant information (MA)

Expt 2: Use of internal (pictorial) or external (global surface) information?

- Two major compensation hypotheses:
  - Pictorial compensation

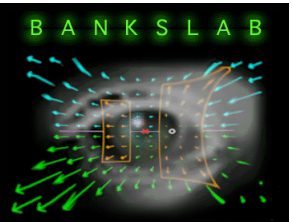


  - Global surface compensation
    - Calculate picture's slant at center (from surface cues: e.g. stereo)
    - "Undo" obliqueness of view



Kubovy (1986)

Changing the camera's projection angle

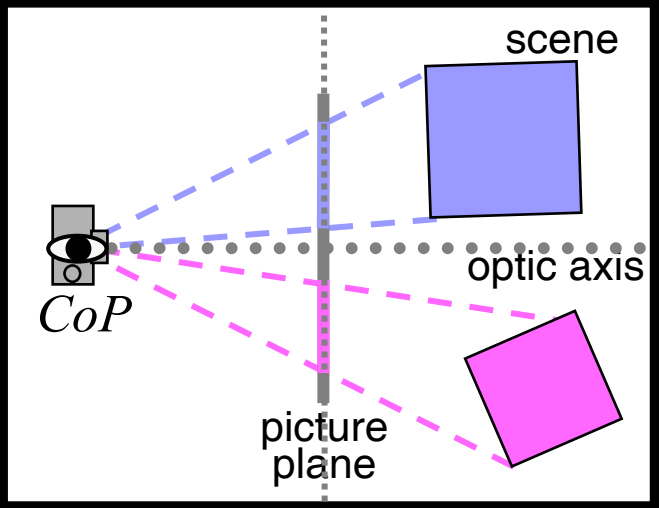


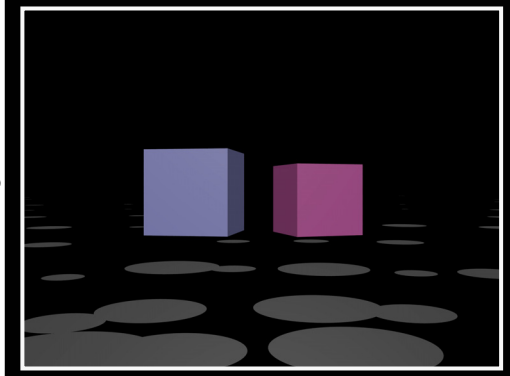
plan view

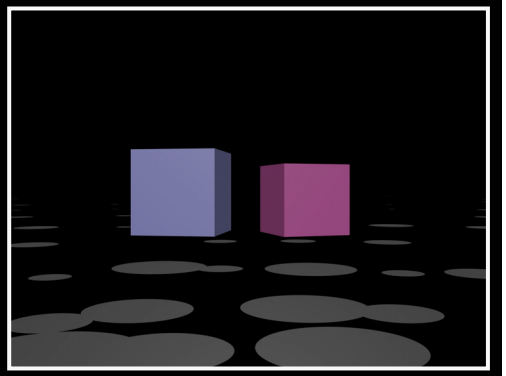
picture (viewed on its normal)

retinal image of picture (eye at CoP)

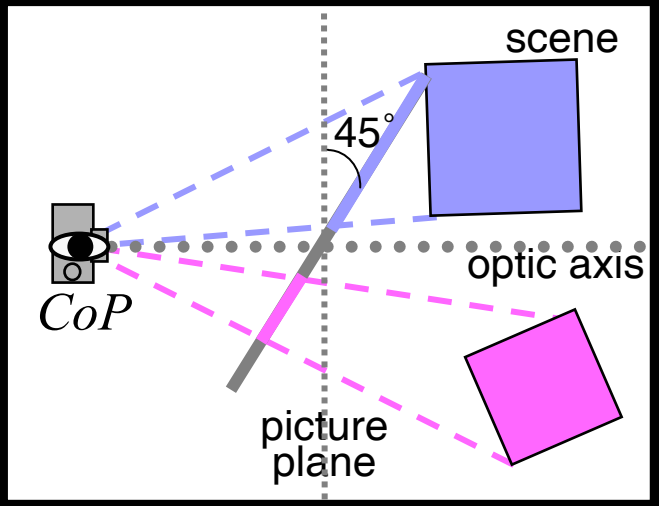
expt 1: fronto-parallel projection

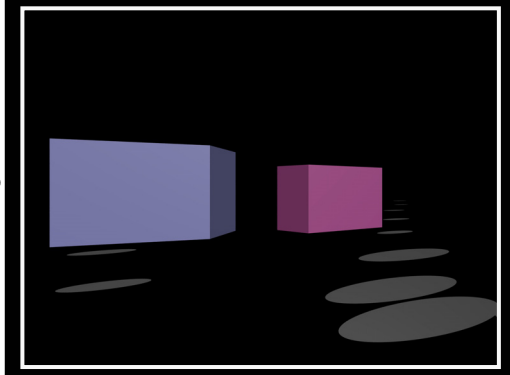


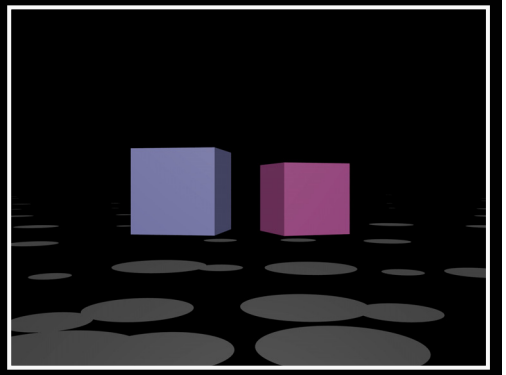




expt 2: oblique projection

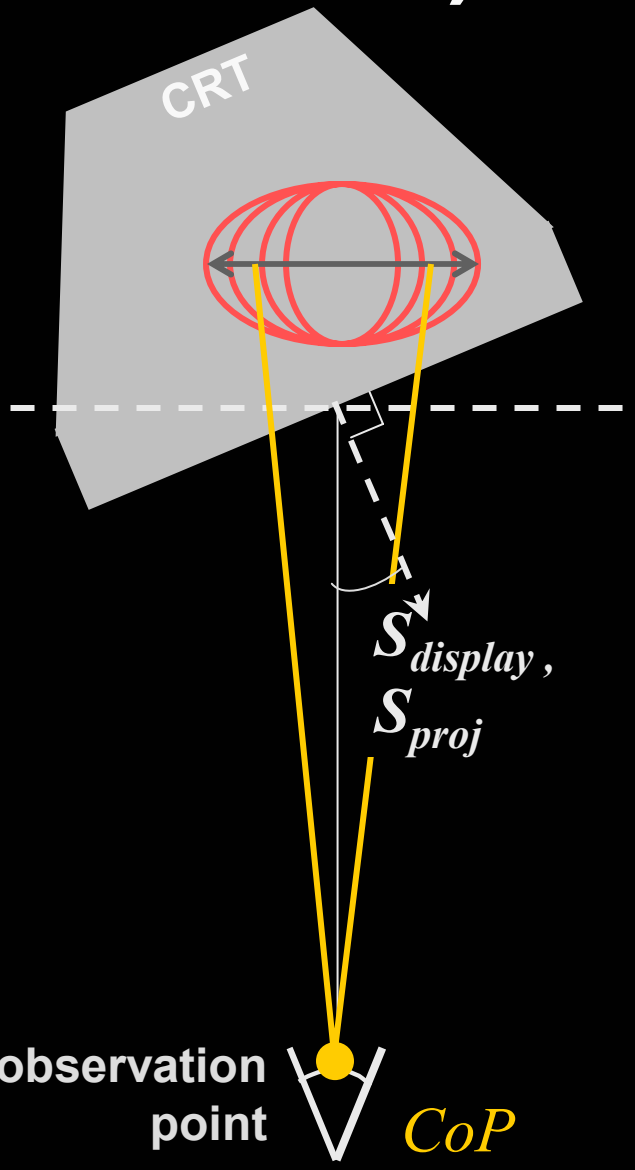


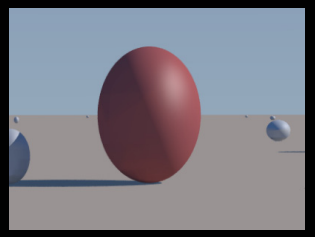


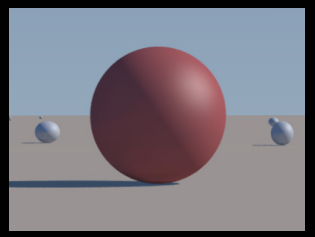


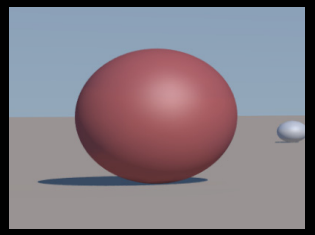
Expt 2: Use of internal (pictorial) or external (global surface) information?

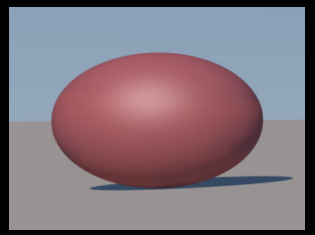
Varied viewing angle $S_{display}$ & projection angle S_{proj} such that observer always at CoP



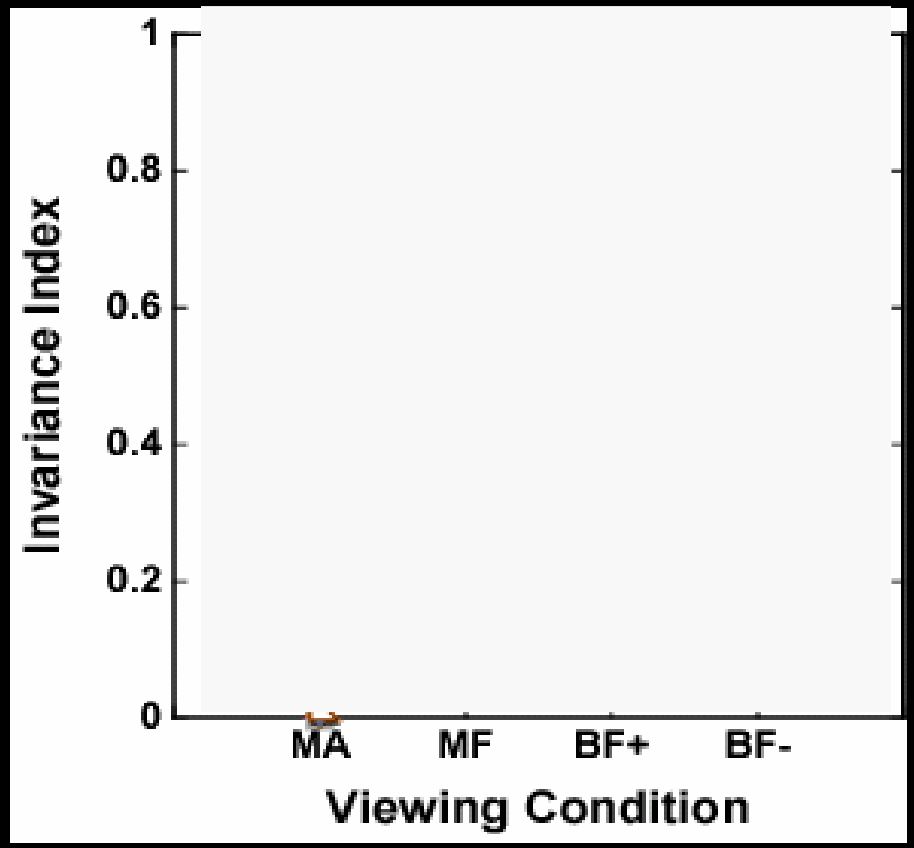








Expt 2: summary data

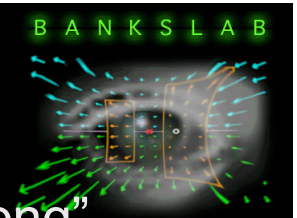


increasing use of surface information

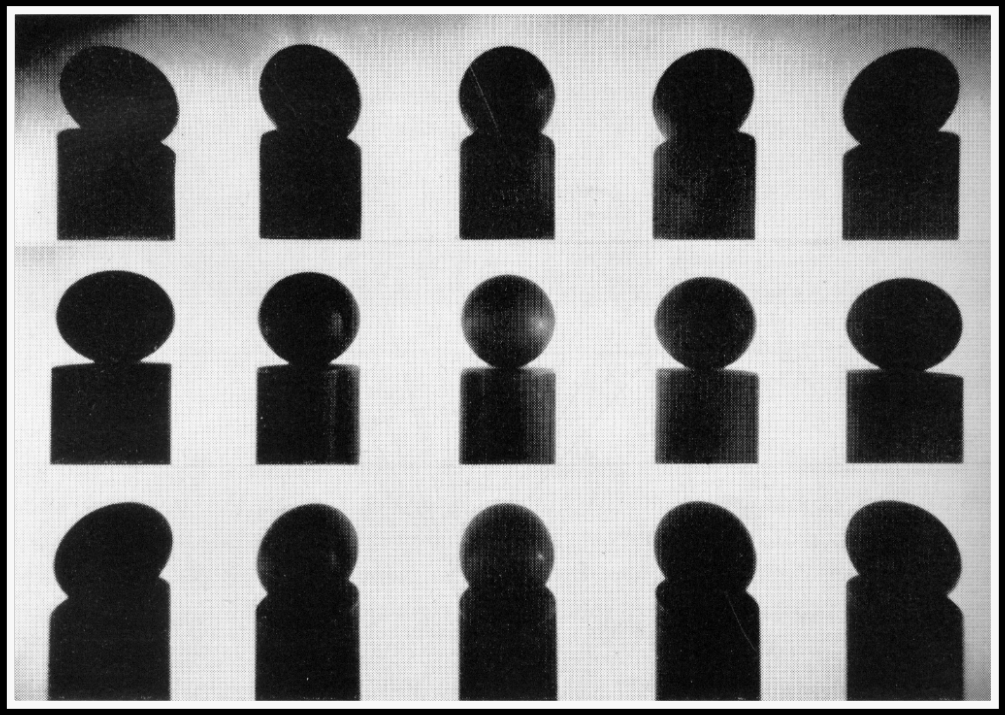
increasing information about picture's slant

In condition where observers are invariant (BF), clear use of global surface (not pictorial) information

Conundrum



- Objects look “right” when viewed (binocularly) from the “wrong” place (non-CoP)
- Observers compensate using information about the picture’s slant

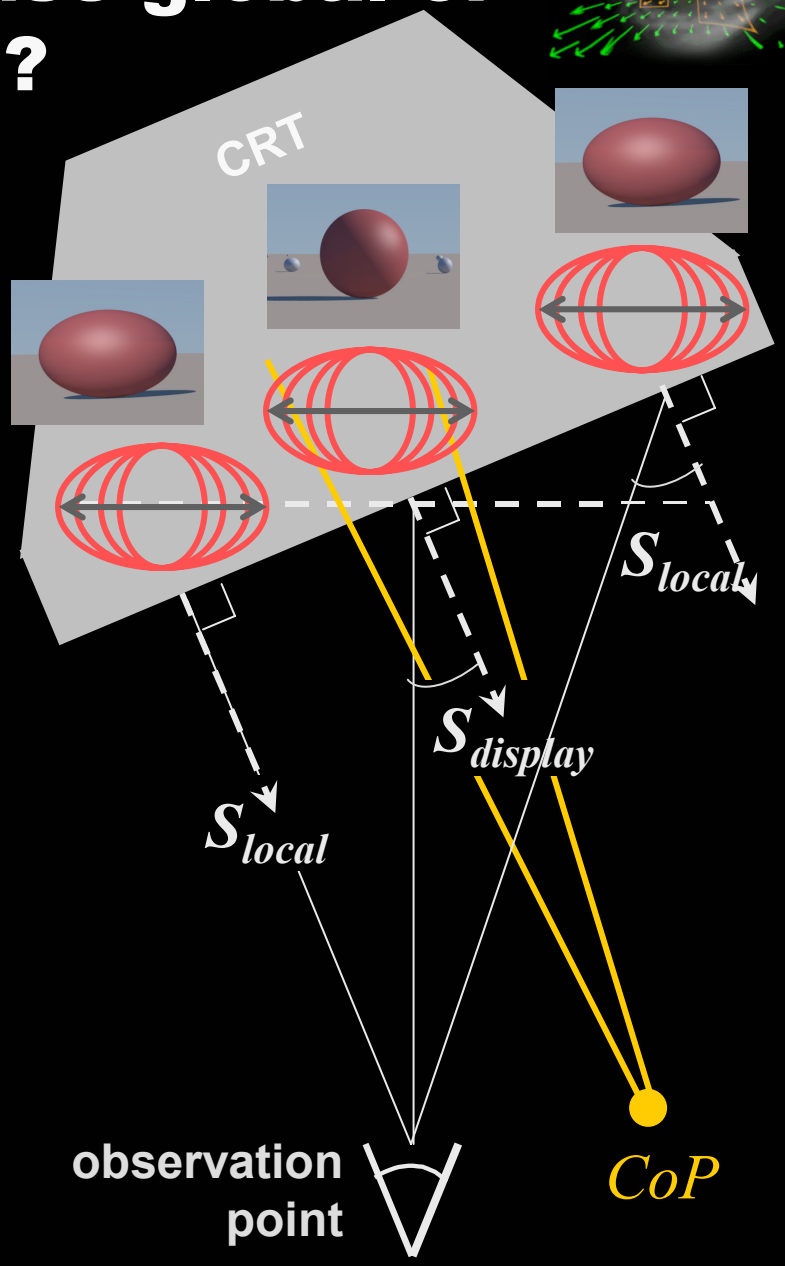


Pirenne (1970)

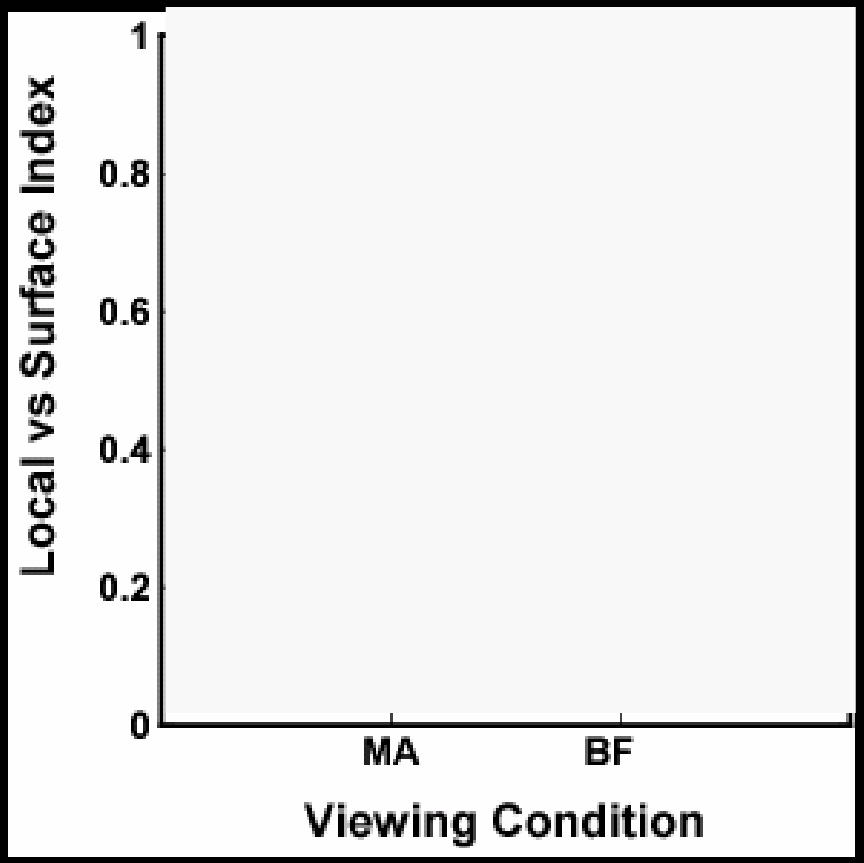
- Eccentrically placed objects look “wrong”, even when viewed (binocularly) from the “right” place (CoP).
- Local surface slant model could account for both these phenomena

Expt 3: Does invariance use global or local surface information?

- Global surface compensation:
  - account for $S_{display}$, angle between line of sight & surface normal at center of picture
- Local surface compensation:
  - account for S_{local}, angle between surface normal & line of sight at region of interest
- Hypotheses can be disambiguated by varying test object eccentricity for an oblique observer



Expt 3: summary data

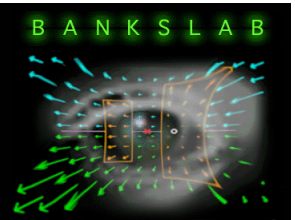


increasing use of local-slant information

increasing information about picture's slant

In condition where observers are invariant (BF), invariance achieved by using local (not global) surface slant information

Summary

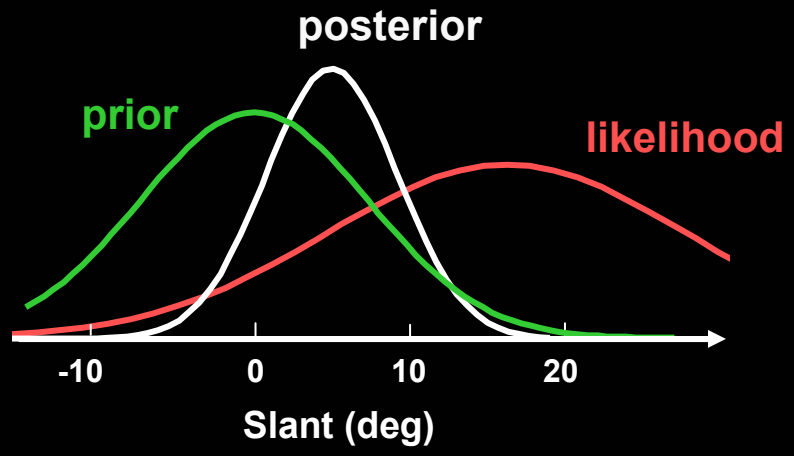


1. The visual system is invariant to viewing position, such that pictures viewed from “wrong” positions look “right”.
2. It doesn’t use traditionally hypothesized approaches.
3. Instead, it uses the local surface slant at the region of interest, even when it leads to the “wrong” percept from the “right” location.
4. Our proposed local-slant model could be described by a Bayesian observer:

$$p(S \mid I) \propto p(I \mid S)\, p(S)$$

I = input to eyes

S = local picture slant



Interesting implications

- Explains anamorphic effect
- Explains wide-angle effect in photography (& traditional use of 50mm focal length)
- Where to best view pictures & movies

The Ambassadors, Holbein, 1533

Ongoing related experiments

- How does the visual system compensate when the picture is in stereo?
- Can the local surface slant model explain the pointing phenomenon?
- Ideal shape for display surface?

Thank you!

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http://bankslab.berkeley.edu