Visual Perception & Display

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Flight & Ground Vehicle Simulation Course – 2017

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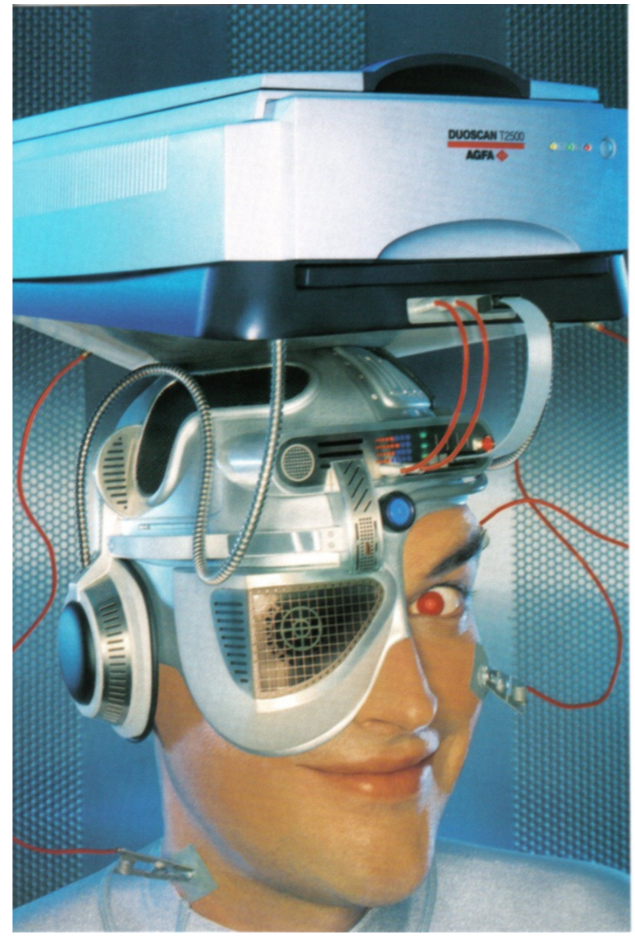
Replicating the visual world

- What's taken for granted in the real world must be provided with OTW *visual simulation*
  - Accurate depiction of visual environment
  - Database, IG, & <u>display</u> all play essential roles
- Perceiving & interpreting visual environment are critical to vehicle piloting. Enablers:
  - Head-mounted sensors (eyes)
  - Selective spatial, temporal, and energy sensitivities
  - Eye & brain processing
  - Knowledge & experience

How we'll proceed

- How displays accommodate head and eye geometries
  - People differences => Adjustments
  - Vision: Instantaneous FOV vs. Total FOV
  - Binocular vision => *Vergence* issues
  - Eyes swivel in head; Head swivels on body
- Light & image characteristics
  - How does vision respond to attributes of imagery: energy; spatial; temporal?
- Visual processing
  - Levels of perception
  - Modes of visual information processing
  - Judging depth & distance
- Research Initiatives



People differences

- People variations affect HMD design
  - Circumference of head
  - Height of forehead
  - IPD – not just HMDs!
  - Overall accommodation
  - Left/right eye focus
  - Allowance for eyeglasses

Adjustment: HMD

- People differences important with HMDs
  - Account for head shape and side-by-side eye layout.
- Adjustments include:
  - Display fit on head (size choice; adjustment) – Like picking a hat!
  - Forehead adjustment of oculars
  - Distance of oculars from face
  - Left/right eye focus
  - Interocular separation (IPD)

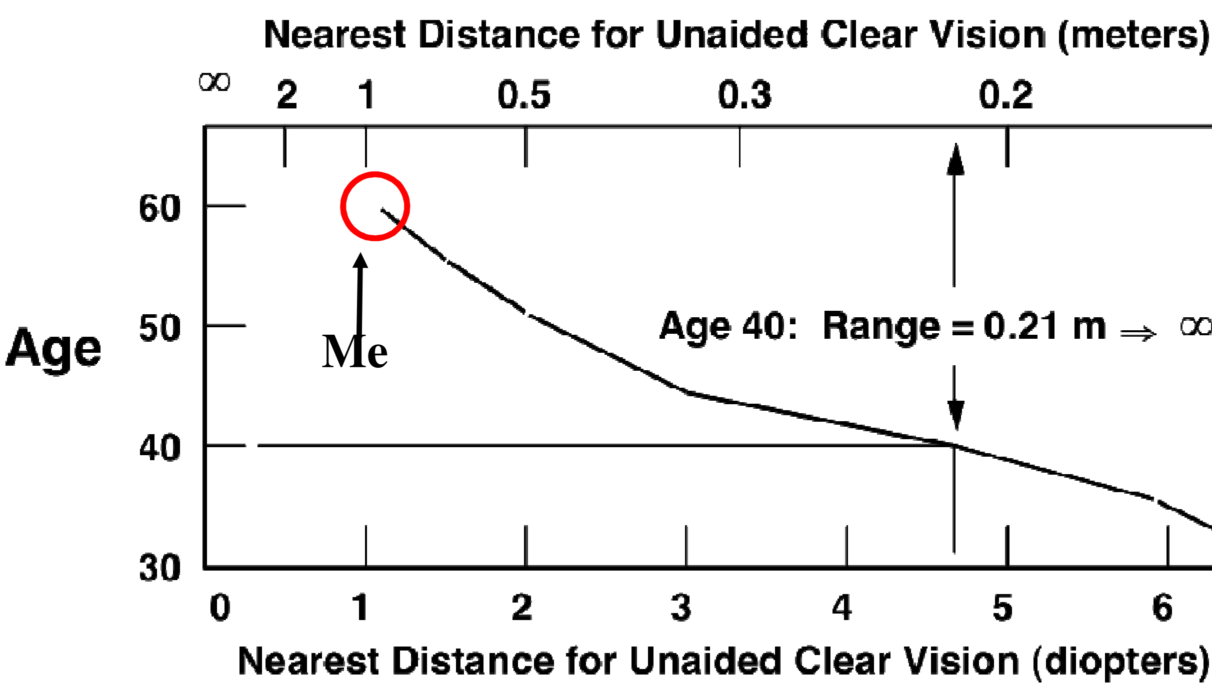
Interocular variation = ±20%

Population	Sample Size	Percentile 1	2.5	50	97.5	99	Range
Air Force Flight Personnel	4057	55.5	56.6	63.2	70.7	72.1	51–76
Army Drivers	431	52.1	—	58.9	—	66.0	—
Females	Not Given	—	53.3	63.5	71.1	—	—
Image Interpreters	61	57.2	58.4	64.9	71.4	72.6	57–73

(All dimensions = mm)

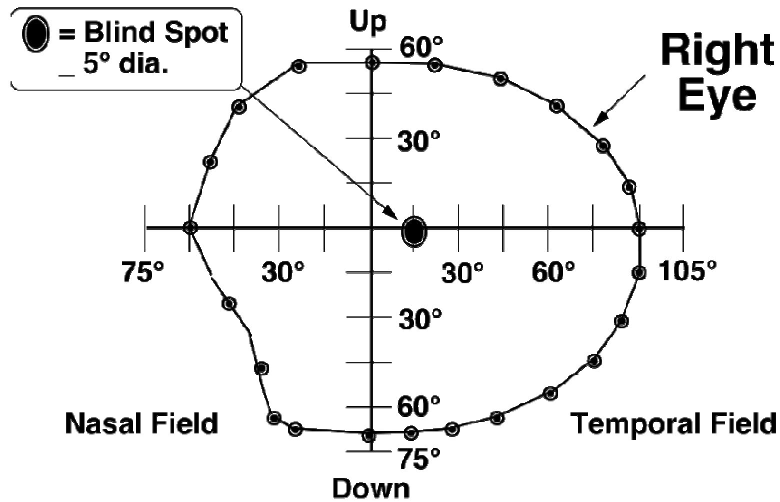
Accomodation & age

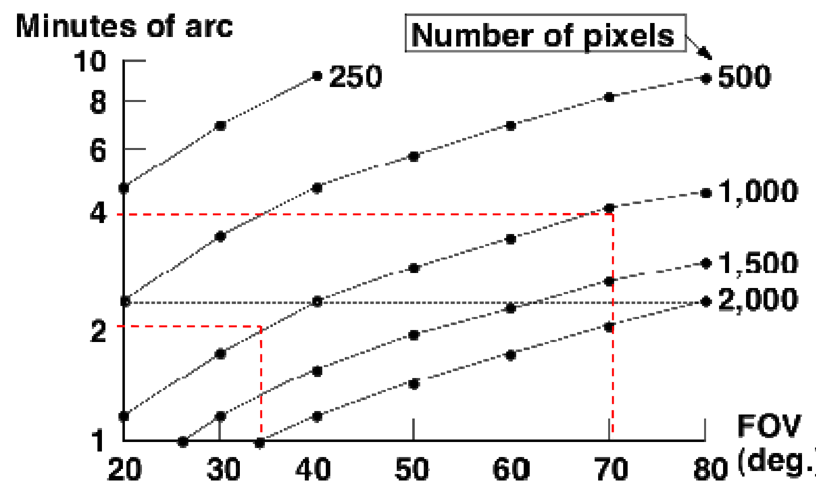
Accommodation range decreases with increasing age



Visual Field-Of-View (FOV)

- Field Of View (FOV)
  - IFOV: 200^{o} H x 135^{o} V
  - Total FOR: Full sphere
  - In simulator, cockpit windows limit FOR
- FOV vs. Resolution trade-off
  - Ex: 1000 pixels ->
    - 70^{o} @ 20/80
    - 35^{o} @ 20/40

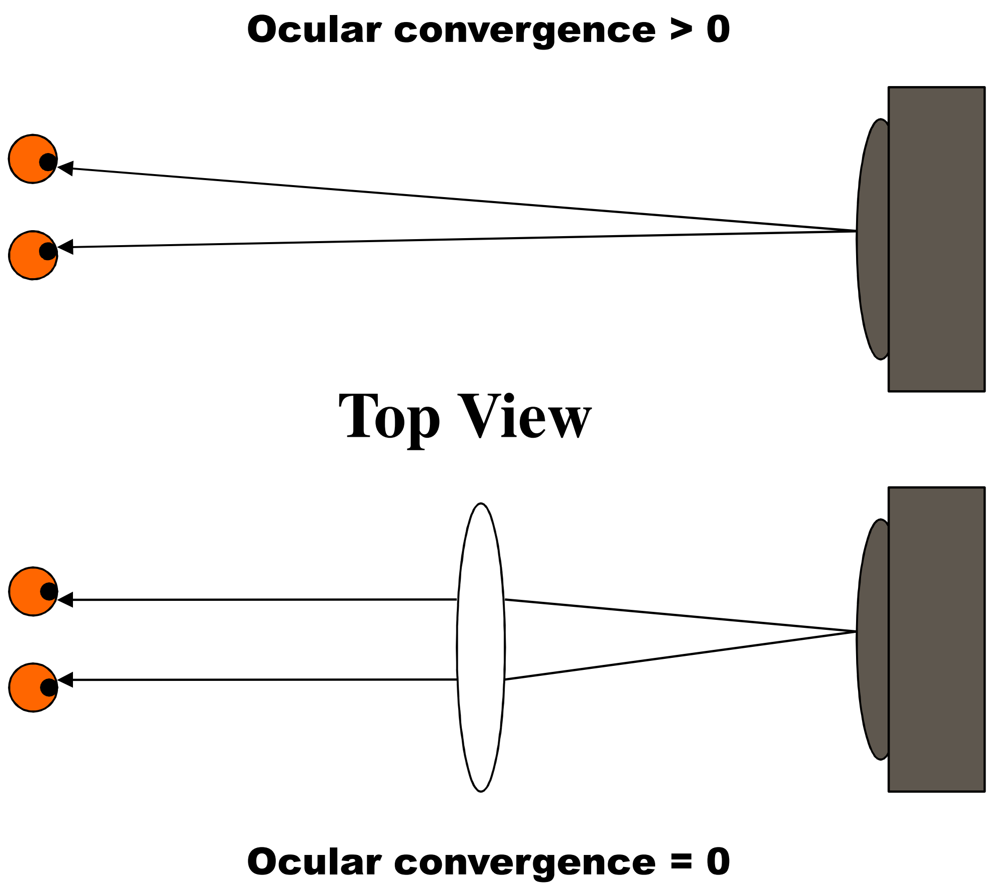




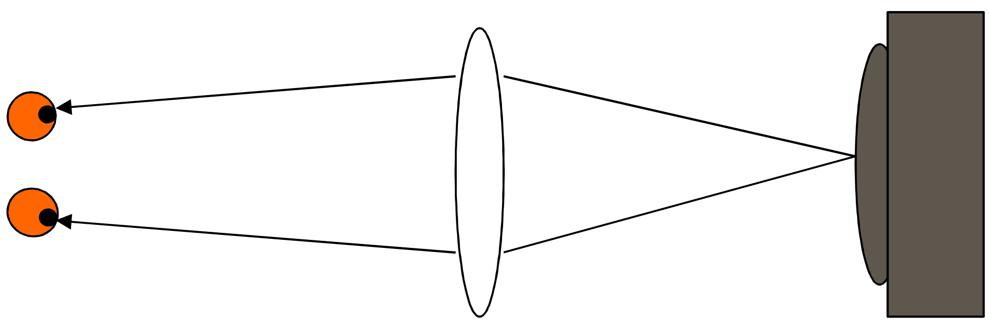
Virtual image displays

- Display in which the image is viewed through an optical system
  - Found in both HMDs and standard displays
  - Characterized by spherical mirrors & lenses that bend (refract/reflect/diffract) light rays
- "Vergence" arises from binocular vision
  - Measure of ocular tilt for binocular fusion
  - In real world, provides distance cueing
  - Display imperfections can lead to problems

Vergence => Binocular Fusion



Problem: Ocular divergence



Ocular convergence < 0

- Divergence doesn’t occur in nature, but it can in visual simulation!
- Severity a function of amount & duration (a little bit is OK)
- Generally not uniform across display. Also, function of IPD
- **Rule of thumb**: Keep divergence away from center of FOV

HMD weight/inertia problem

- Many styles of HMD
  - Trade-offs involve weight & inertia vs. FOV, resolution, & ruggedization
  - Most now use LCDs or OLEDs

N/A

5.5 lbs with helmet

Gear VR - 12 oz.

1.75 lbs.

Cautions (from Gear VR User Manual)

- Do not use the Gear VR when you are tired, need sleep, are under the influence of alcohol or drugs, are hung-over, have digestive problems, are under emotional stress or anxiety, or when suffering from cold, flu, headaches, migraines, or earaches.
- We recommend seeing a doctor before using the Gear VR if you are pregnant, elderly, have pre-existing binocular vision abnormalities or psychiatric disorders, or suffer from a heart condition or other serious medical condition.

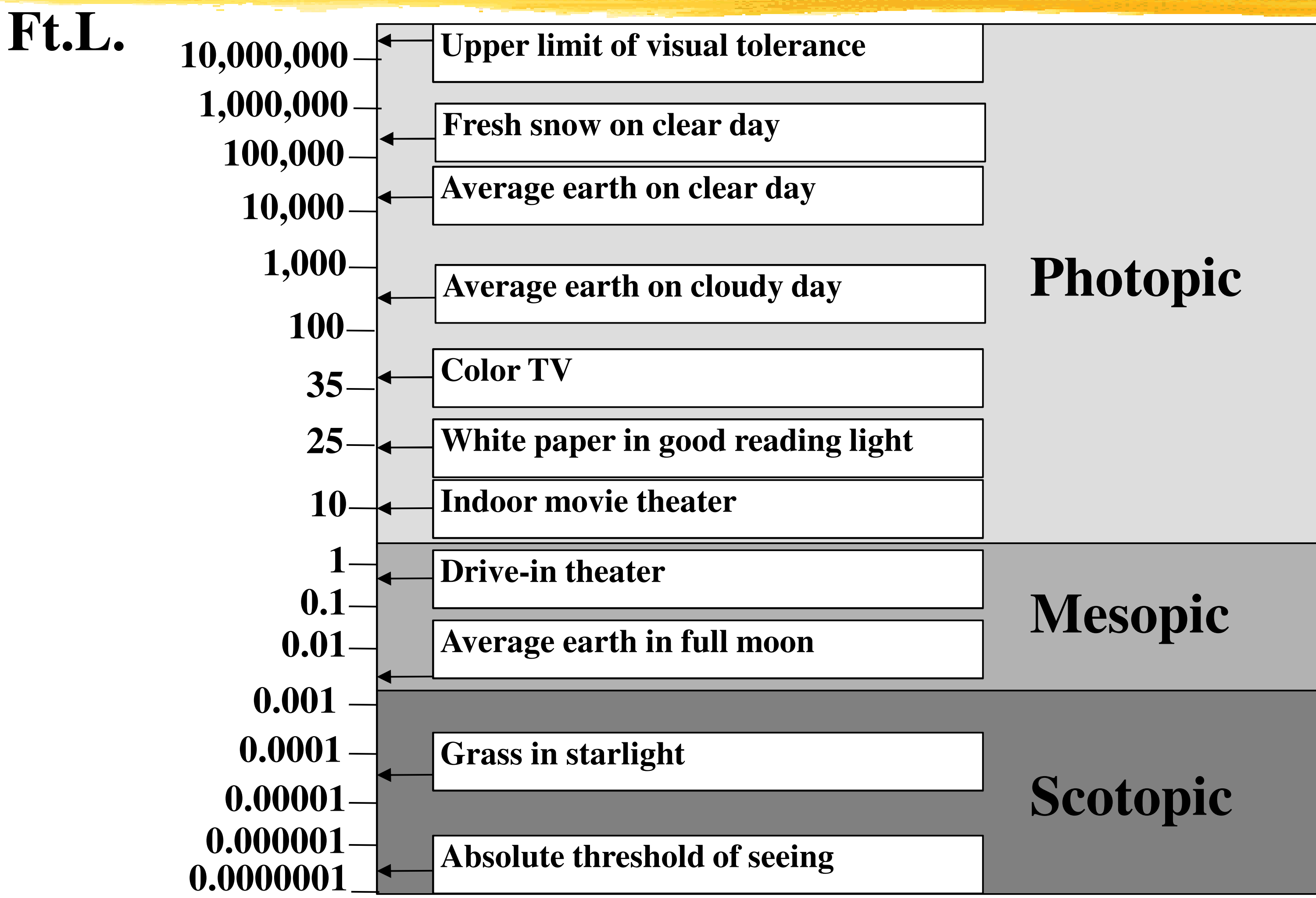
Light & image characteristics

- How does vision respond to different image attributes?
  - Energy
  - Spatial
  - Temporal

Luminance sensitivity (energy)

- Dynamic range of eye is ~14 orders of magnitude
- Two types of photo-receptors:
  - Rods (most sensitive, but B/W)
  - Cones (color sensitive; highest resolution)
- Three regions of luminance:
  - Photopic: > 3 ft.L. (primarily cone vision)
  - Mesopic: 0.0003 ft.L < Br < 3 ft.L (rods/cones)
  - Scotopic: < 0.0003 ft.L (rods only)

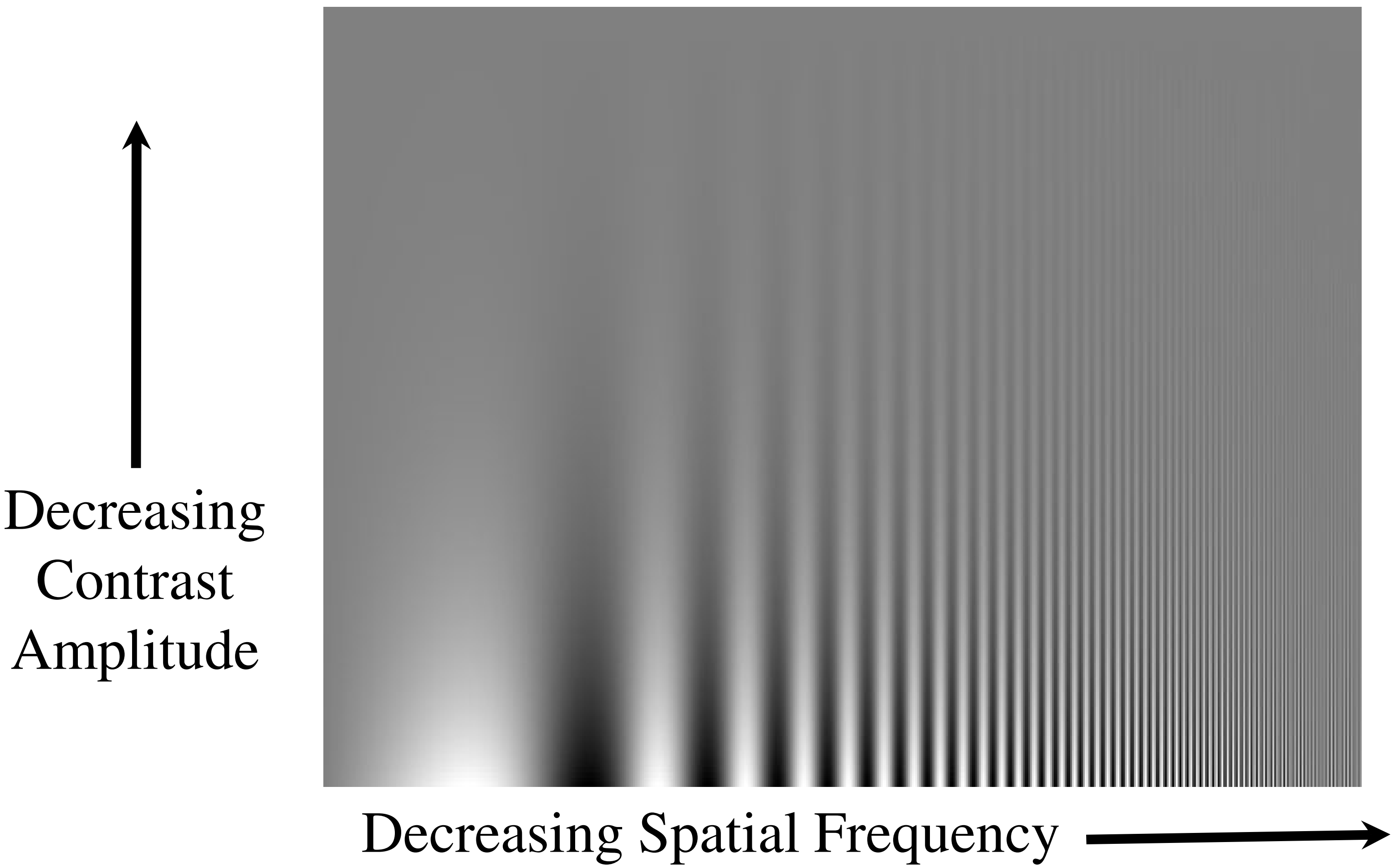
Levels of luminance



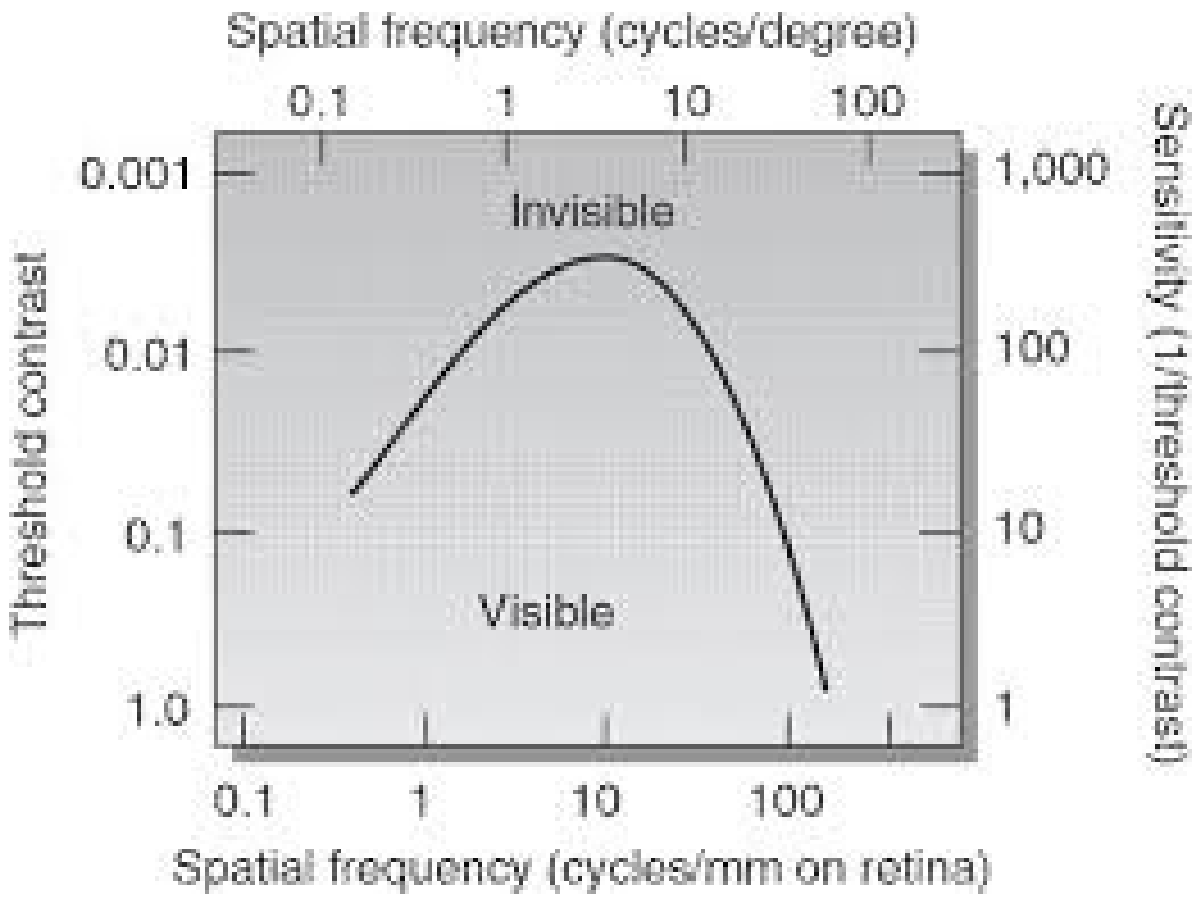
Contrast (energy)

- Contrast = $(I_{MAX} - I_{MIN})/(I_{MIN})$
  - One of many definitions
  - Minimum detectible ~ 0.2
  - Contrast sensitivity a function of spatial frequency
  - Peaks at 4 cycles/degree

Contrast Amplitude vs. Spatial Frequency



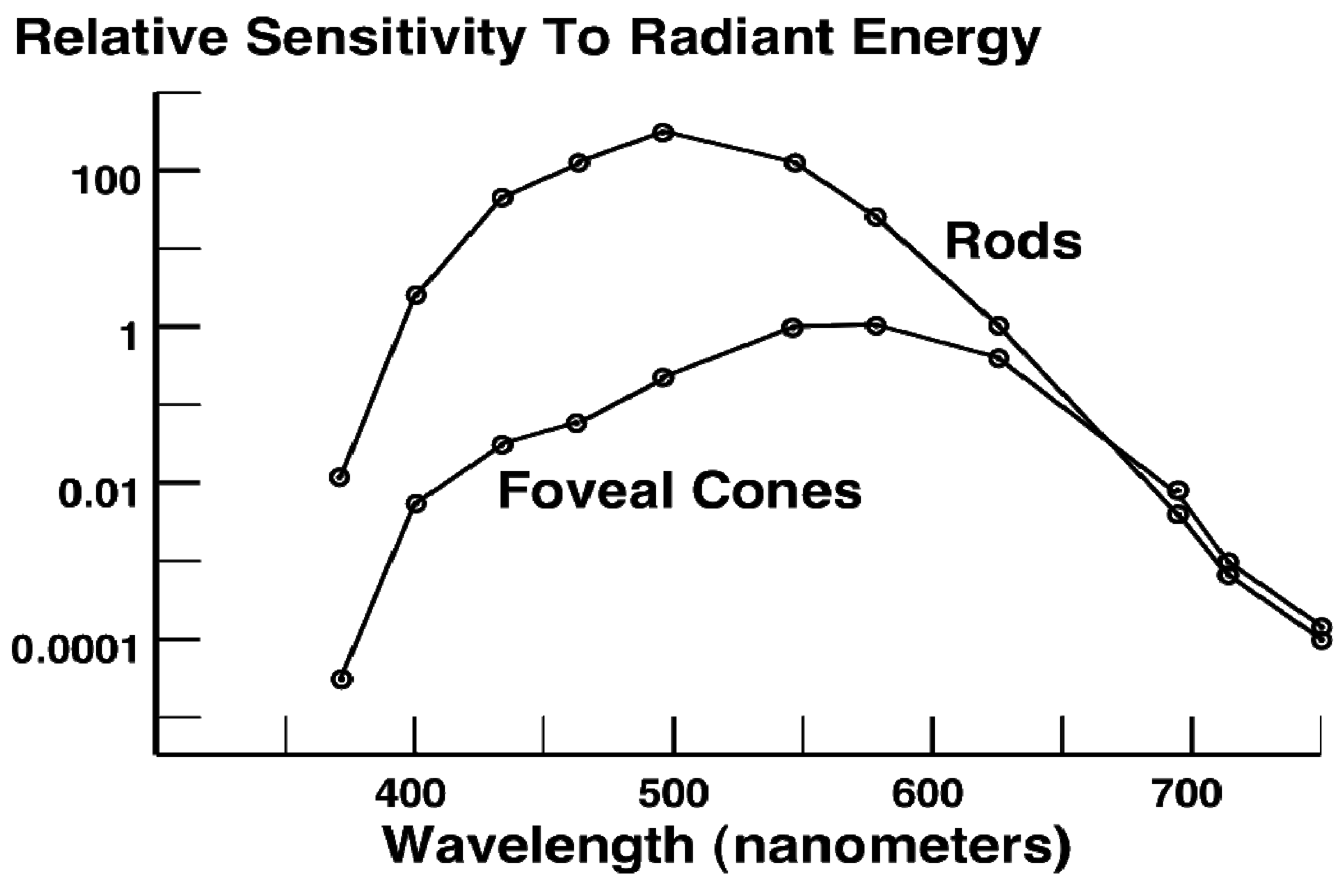
Contrast Sensitivity



Challenge of contrast

- Contrast of typical scene = 160
  - Contrast sometimes as high as 760
- Compare: Contrast of simulator display 7 –> 60
- Most serious energy deficiency in displays today!

Color (energy)



Resolution (spatial)

- Acuity (2-D) of unaided eye
  - ~1 arc-minute = 1/60th of a degree
- Resolution dependent on many factors;
  - Static vs. dynamic – more on this later
  - Position in visual field
  - Color vs. B/W; luminance; contrast
  - Individual differences
- Johnson Criteria - Seek to establish resolution standards for raster sensors

Levels of discrimination

- Detection
  - Object is present
- Orientation
  - Orientation discernible if asymmetric
- Recognition
  - Class discernible (house, truck, man, etc.)
- Identification
  - Target describable to limit of observer's knowledge (motel, policeman, etc.)

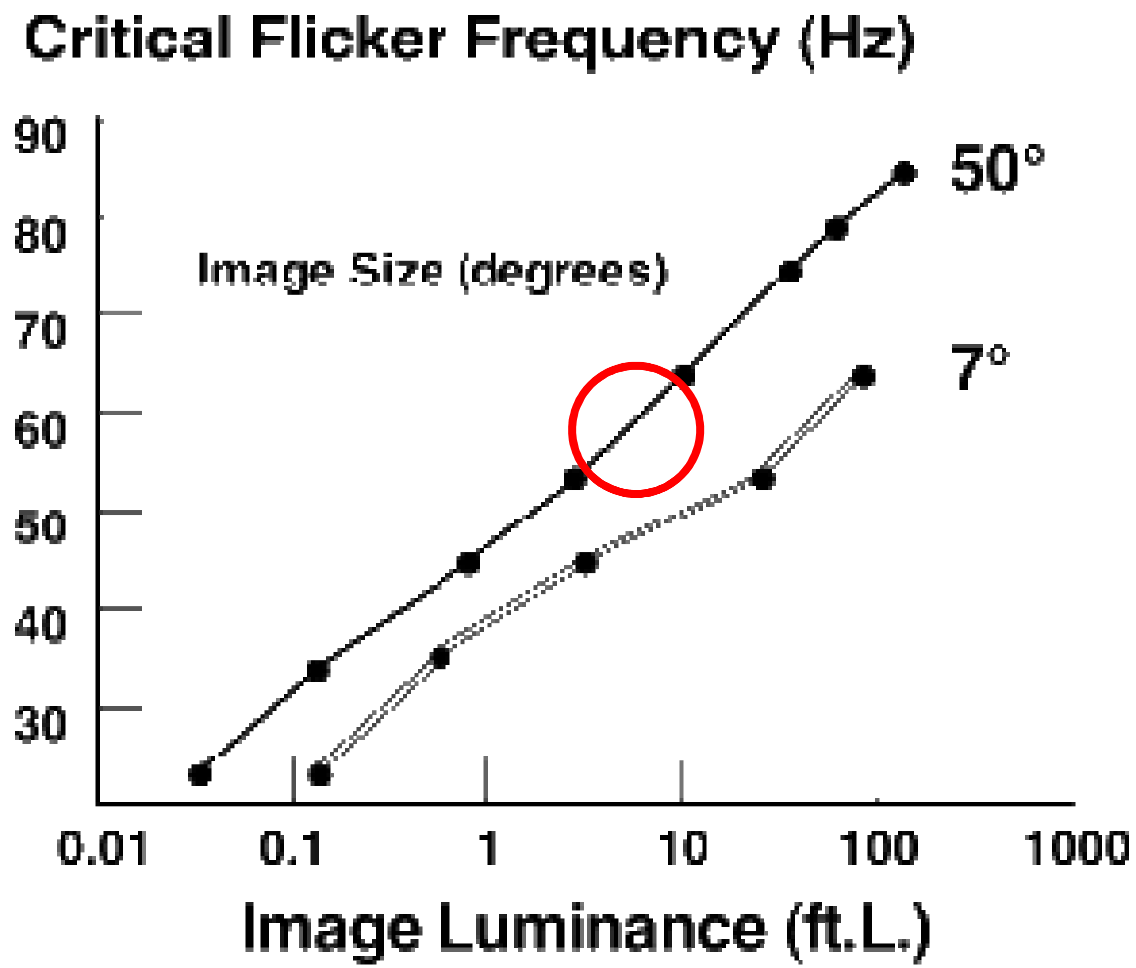
Pixels & Information

- Pixels represent units of information
  - If objects subtended by more pixels, then better clarity.

Flicker (temporal)

- If stroboscopic images are repeated quickly enough, the eye integrates the discrete images
  - Continuous, non-jumpy imagery perceived
  - Flickernot apparent if above a Critical Flicker Frequency (CFF)
  - CFF affected by image persistence (τ_r and τ_d)
    - Generally, 60 Hz adequate for simulation

CFF as f(Luminance; size)



Motion Blur

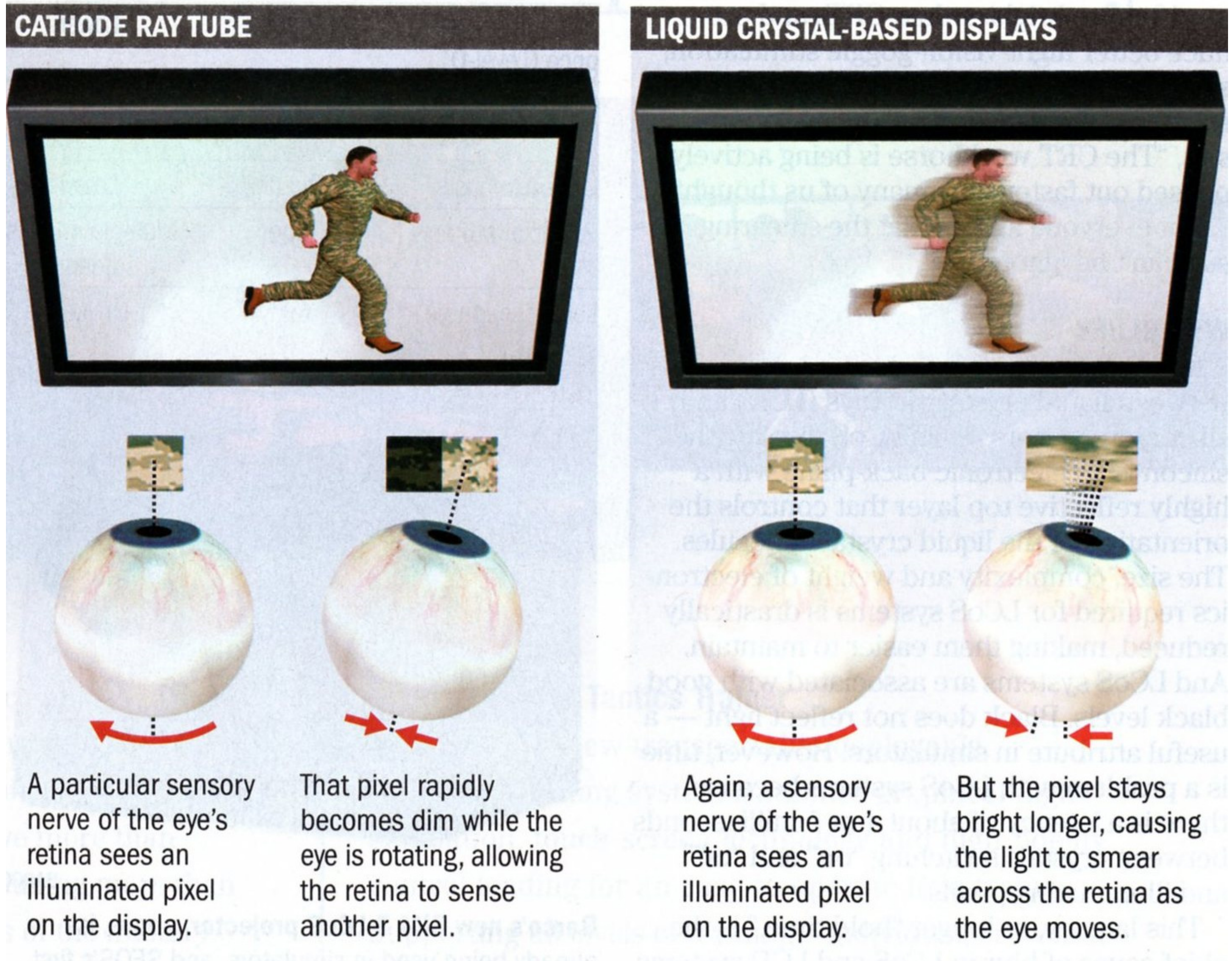
- Blur (degradation of acuity) of a rapidly moving object in visual scene arises from two causes:
  - Imperfect pursuit tracking causes degradation of ~0.5 arcmin per 10^{o}/sec of stimulus motion
  - Excessive τ_r and τ_d of pixel luminance
- Impact: Reduction of dynamic resolution below that of static resolution
  - An important consideration when choosing among CRT, LCD, LCoS, and DLP displays

Short history of motion blur

- Blurring of CRT displays used to arise from phosphors with long decay times
  - Ghosting; persistence; tailing of lights
  - Solution: Faster, less color-saturated phosphors
- Blurring of early LCD displays for same reason
  - One solution –> heating LC, but shortens life
- Short persistence at odds with high LCD brightness
  - Decrease in cell thickness -> τ_r and τ_d decrease and modulation more difficult.

Blurring: CRT vs. LCD

Ref: K. Walker, "Brightness vs. Blur", <u>*TSJ*</u> (Oct/Nov 2007) p. 18-22.



Reducing motion blur

- New LCD materials; less viscous
- Reflective vs. Transmissive
  - LCoS; SXRD
  - Double pass!
- Shutter to reduce pixel "ON" state

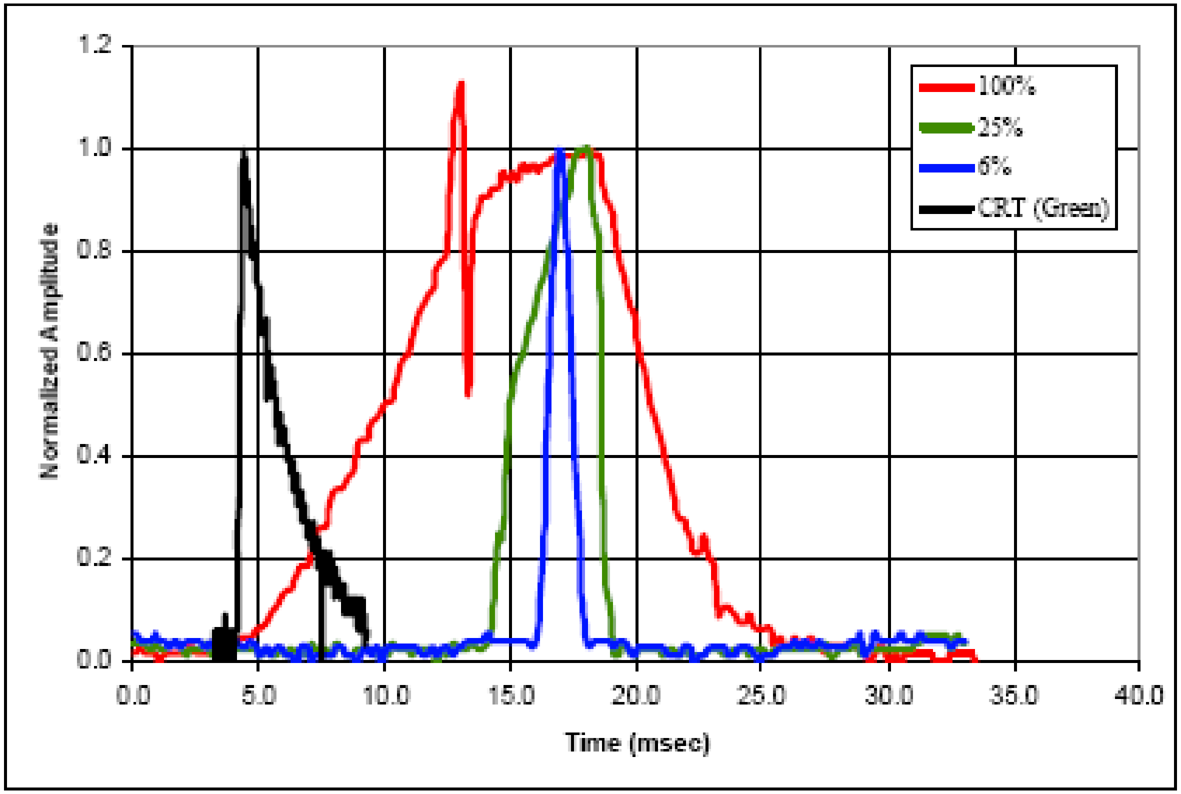


Figure 2. Normalized temporal luminance distributions for three of the five hold-times tested, and for the CRT projector.

from Winterbottom, et. al.

Reducing smear

- Ex: Barco F35 projector
  - Smear reduction via two mechanisms:
    - 120 Hz update rate
    - Either 4, 6, or 8 msec of blanking to reduce duty cycle
      - Approx. 25%, 40%, or 50% frame blanking @ 60 Hz

How we see

- Visual output is combined with vestibular, somatic, proprioceptive, & kinesthetic sensing to produce a stable body-centered reference and ordering of the surrounding environment
- “Seeing” learned at an early age
  - Many learning processes proceed subconsciously
  - Binocular vision aids construction of 3-D world
- Approach:
  - Focal mode of visual information processing
    - Three levels of perception
  - Ambient mode of visual information processing

Visual processing- Focal

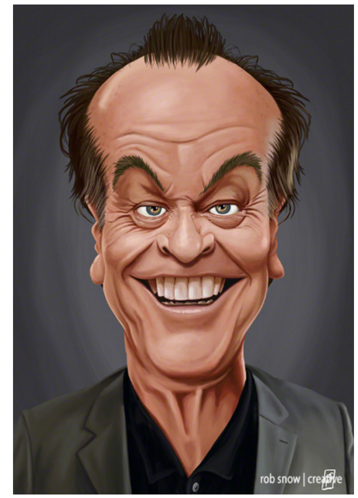
- Focal mode
  - Works only with visual information
  - Uses all spatial frequencies - detail matters!
  - Requires adequate luminance & geometry
  - Requires attention; goal-oriented
  - Answers “What am I looking at?”
  - Examples - Concentration on:
    - Flight instruments or charts for navigation;
    - Airport or road signs while taxiing or driving

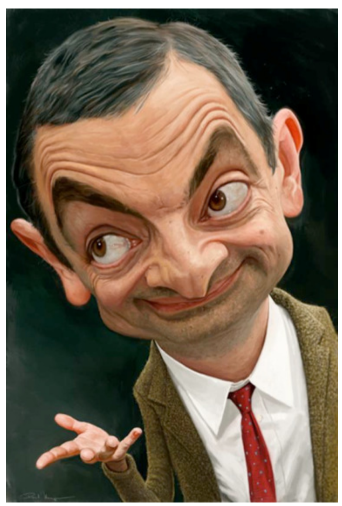
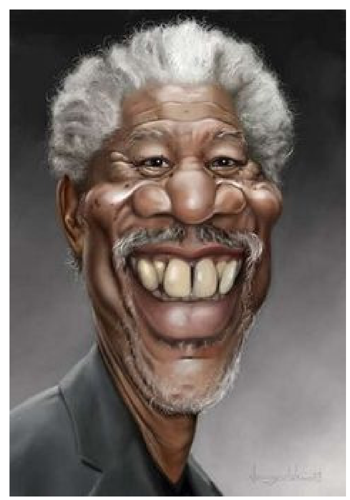
3 levels of focal perception

- Image referenced
  - Based purely on pattern of light entering eyes
- World referenced
  - Seeing things in context; constancy
  - Modifiable by visual experience
- Knowledge referenced
  - Finding meaning, significance; intention; etc.
    - E.g., Friend vs foe identification
  - Easily modifiable by all types of experience

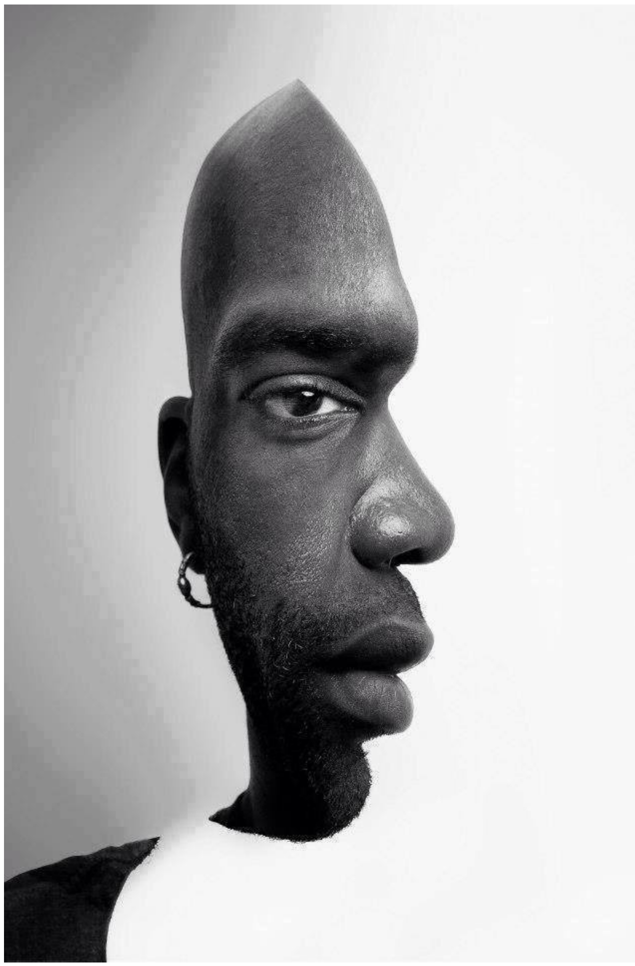
World & Knowledge Referencing

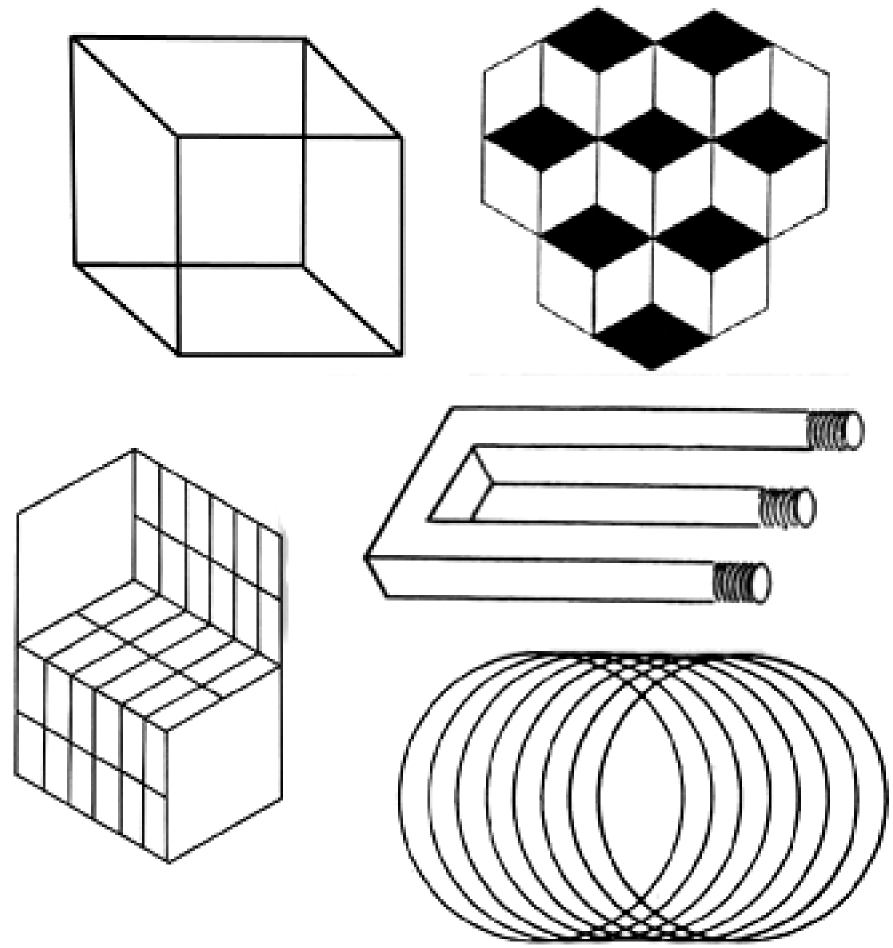



World-referencing confounded





Training => Convert from Image- to World-referenced

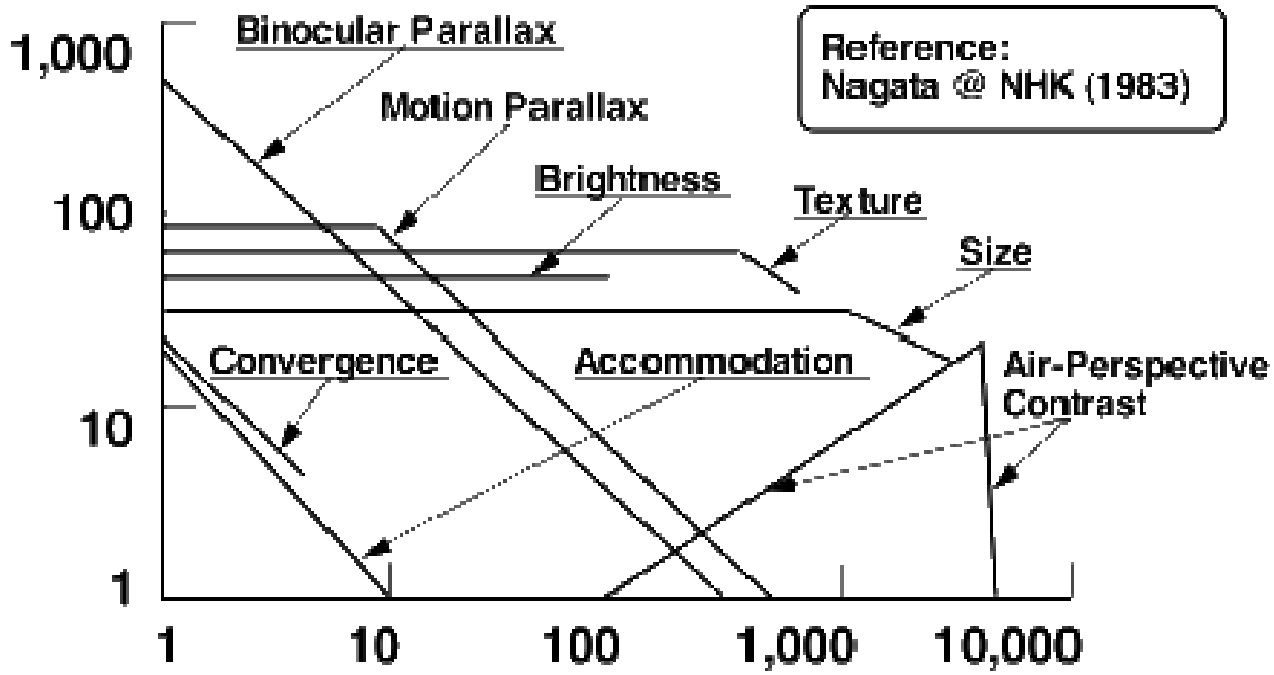
Visual processing–Ambient

- Ambient mode
  - *Situational Awareness* - concerned with “where am I?”
  - Works with vestibular, somatosensory, and auditory info
  - No relation to energy or quality: response “all or none”
  - Improved performance with larger FOVs
  - Conscious awareness is low or none
  - Highly sensitive to motion; will direct “focal” to movement
- Compare:
  - CAVU vs. IMC
  - Driving car while reading map (or talking on phone)

Judging depth/distance

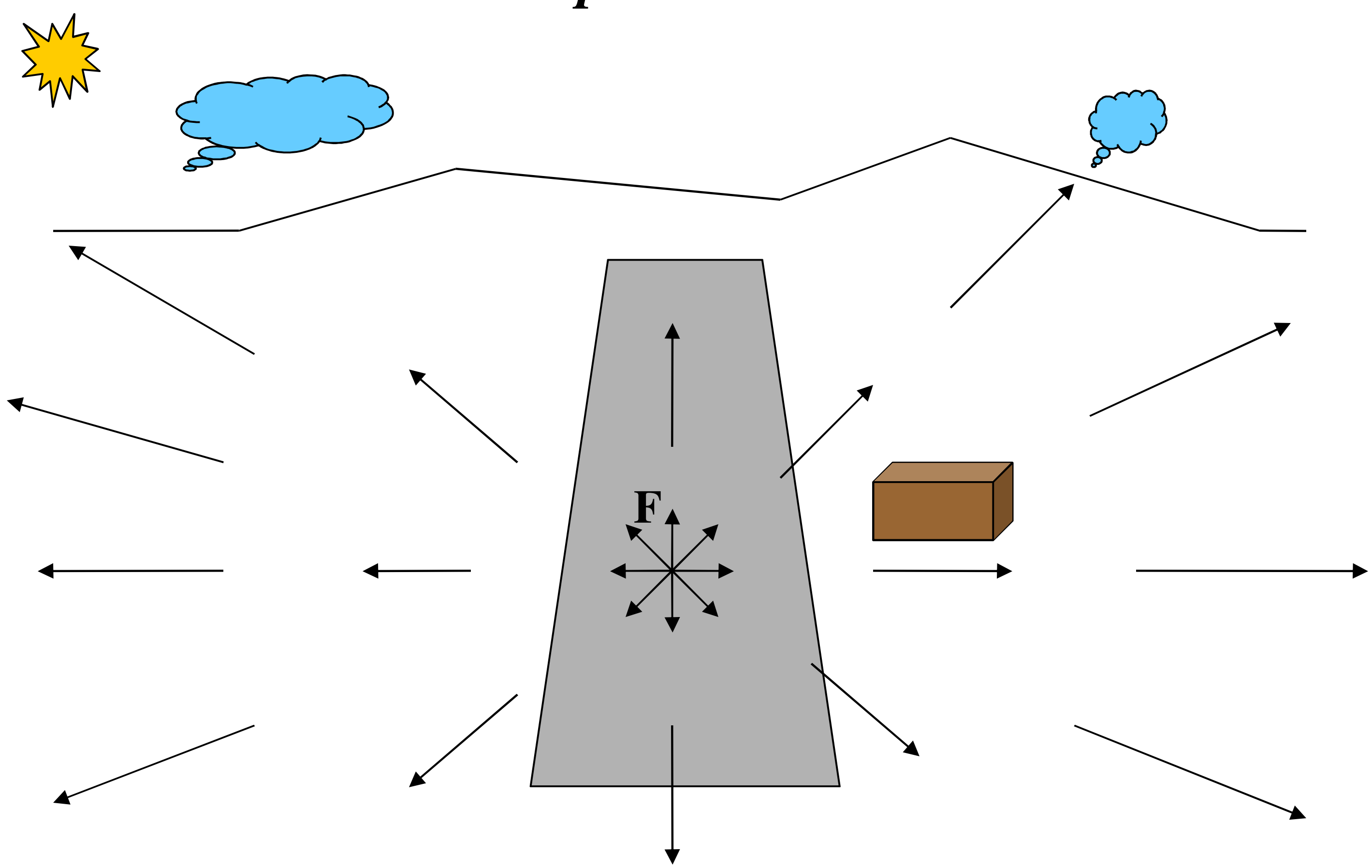
- Depth cues vary in importance as a function of distance
  - Primary => Physiological basis (e.g., convergence)
  - Secondary => Psychological or pictorial basis

Visual Depth Sensitivity

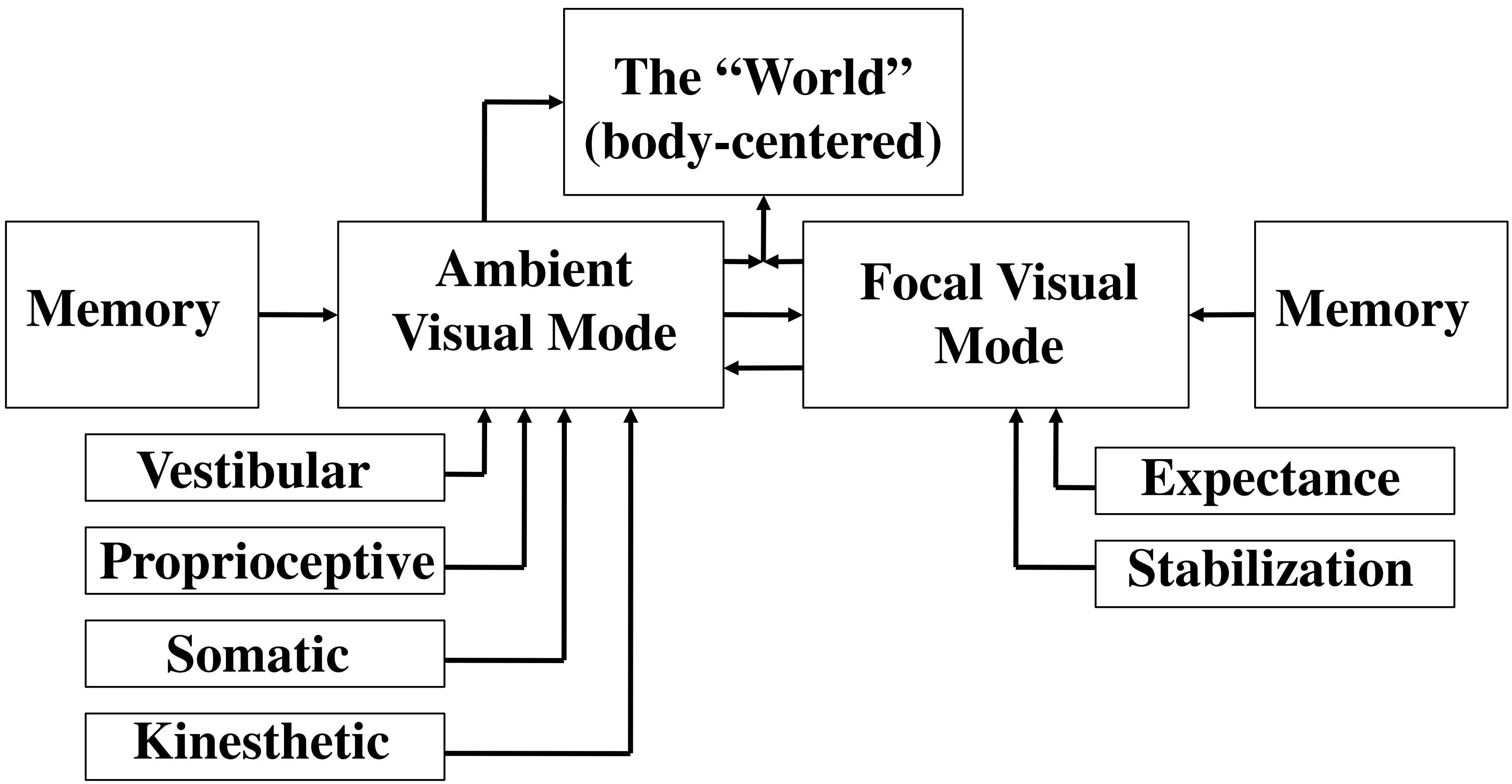


Using retinal motion – Landing

***Radial Expansion* at work**



Sensory Interactions



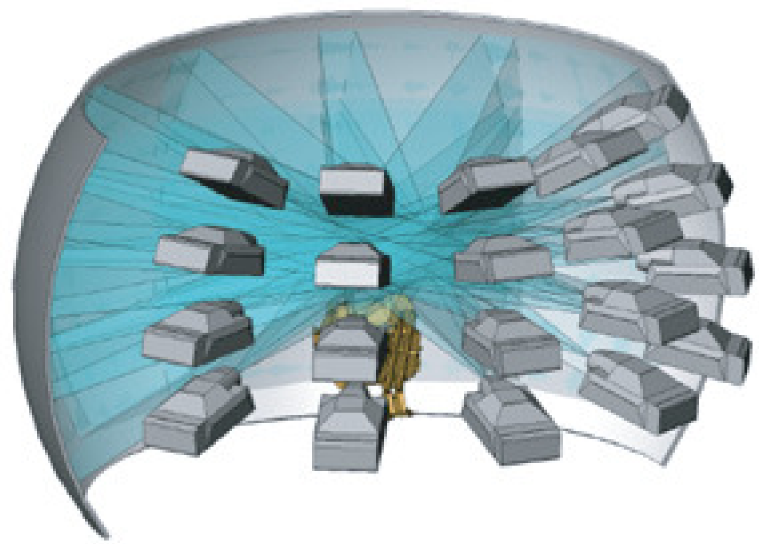
Research Initiative: OBVA

- “Operational Based Vision Assessment” Laboratory
  - Initial funding: USAF 711th Human Performance Wing, School of Aerospace Medicine, and Office of SG
  - NASA/Ames lead agency for OBVA feasibility study
  - Objective: Correlate vision standards to operational performance standards using a synthetic environment
    - Current visual standards date to World War II/I
    - Enable accurate assessment of operational risks associated with vision standards
    - Ensure Airmen have sufficient visual capability for modern operational tasks

OBVA Display

- 20/13 visual acuity necessary
  - 20/10 desired; Proposed projector is Barco* Sim10
- Update rate = 60 Hz; optimal rate still TBD

Current Part-Task Trainer



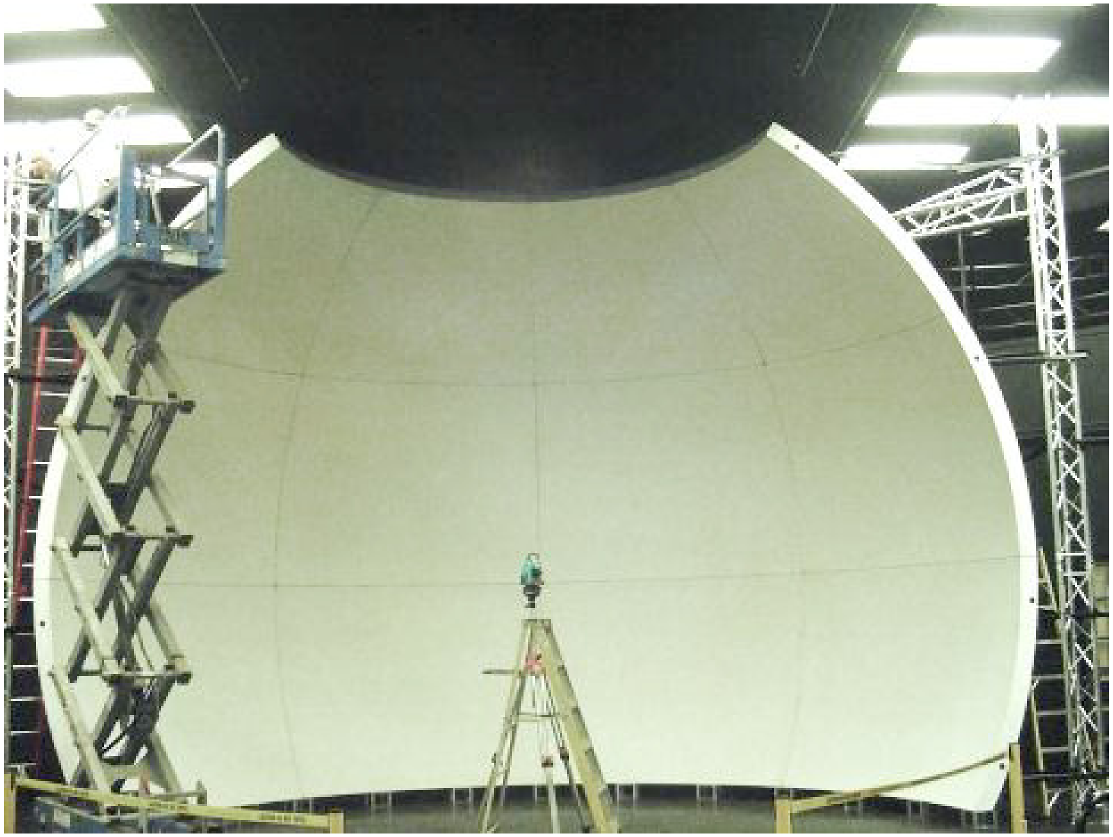
"Potential" OBVA Configuration

OBVA Status - 30 Aug 2013

- Full operational capability at WPAFB, Ohio
- Visual Latency = 32 msec
- Initial research to focus on three capabilities:
  - Acuity
  - Contrast sensitivity
  - Color discrimination (e.g., color-coding friend/foe symbology)
- Should vision standards be tightened or loosened?

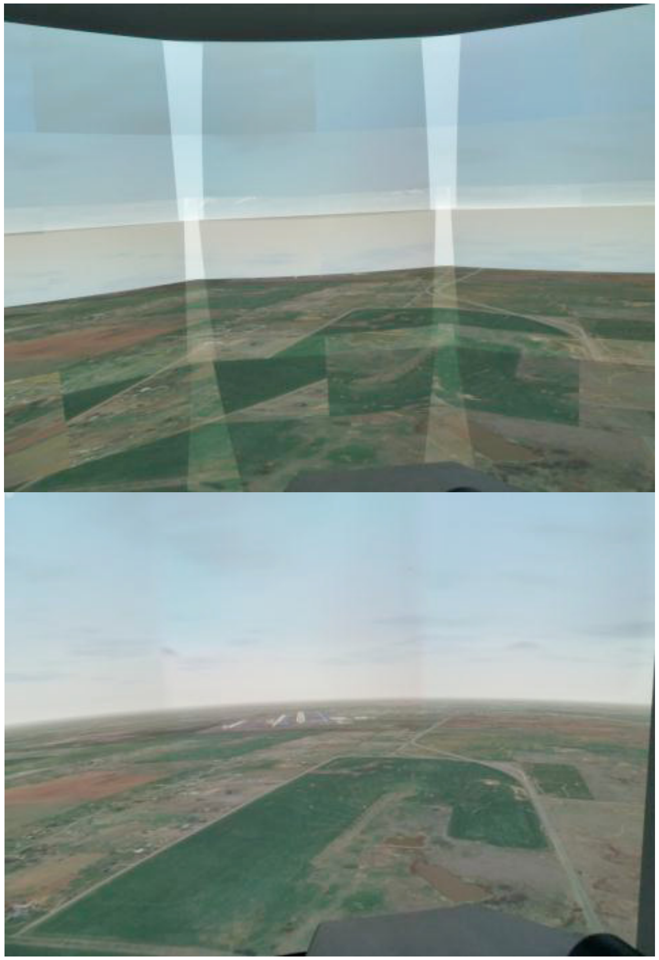
Projection Screen

- Immersive Display Solutions
  - 4m radius
  - 12 fiberglass sections
  - Flat latex paint
  - FOV:
    - 160º H
    - -30º/+60º V



OBVA Projectors

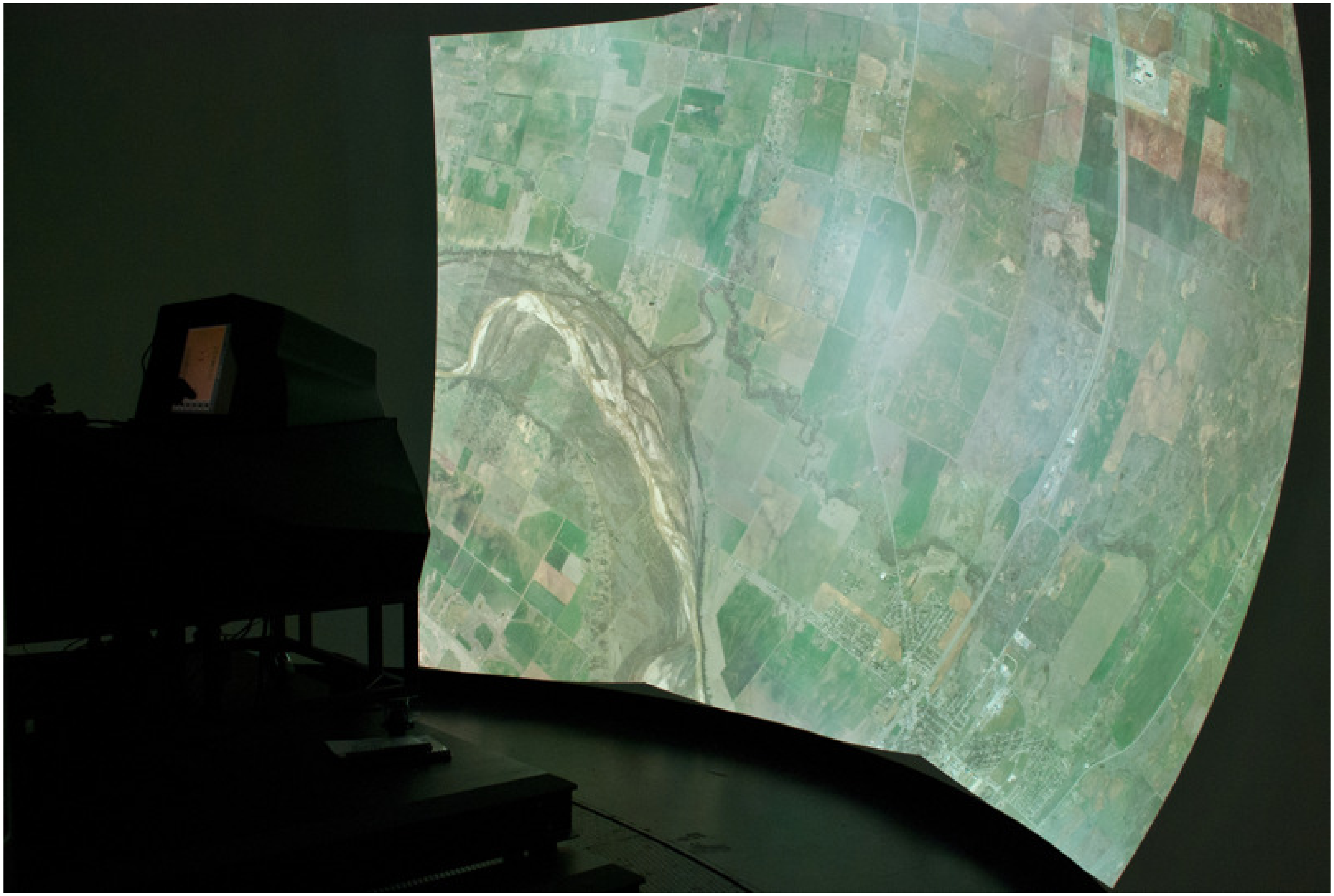
- (15) x Barco SIM10
  - 10 MegaPixels each
  - 0.5 arcmin/pixel
  - Mechanical shutter reduces smear
- Sony SRX and JVC projectors considered
  - JVC: Couldn’t display “aviation red”
  - Sony: LCD shutter => add’l 30% light loss vs. mechanical shutter
  - 1,000 hr life => $5K/projector



Partial Assembly of OBVA

OBVA Projector Structure

OBVA Lab OTW Imagery



Contrast Acuity Tests

High Contrast

Low Contrast

Conclusions

- Simulator displays must account for:
  - Mechanics of vision
  - Variations among viewers
  - Cueing to support visual perception
- Trade-offs necessary:
  - Limits on FOV, brightness, contrast, color gamut, update & refresh rates, resolution, and content
  - Limits on adjustability (e.g., 95th percentile?)
  - Limits on cueing (e.g., no stereopsis?)

References - a sampling

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- James Rader, AFRL-SA-WP-TR-2014-0005, OBVA Final Report (for August 2008 to September 2013).