Black Level Visibility as a Function of Ambient Illumination

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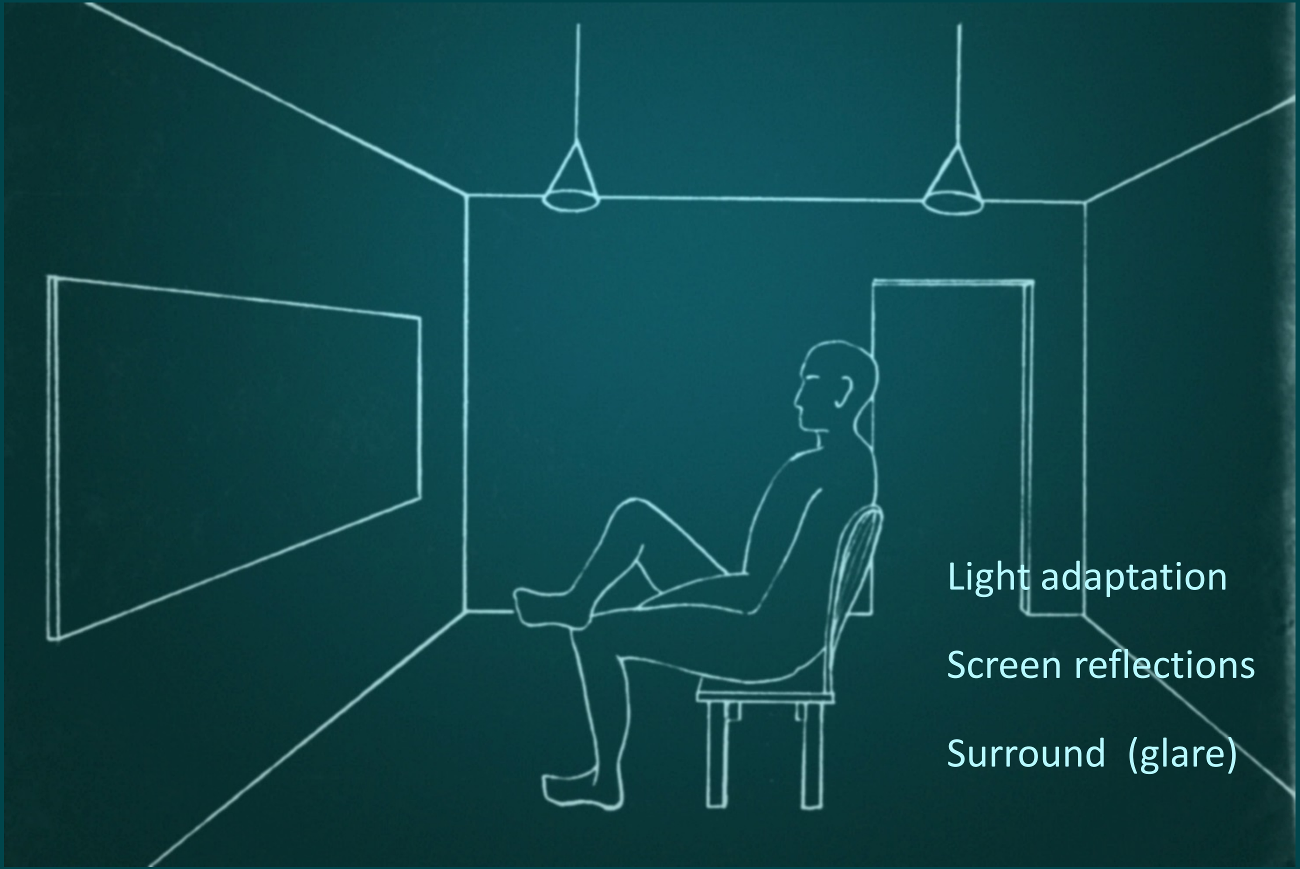
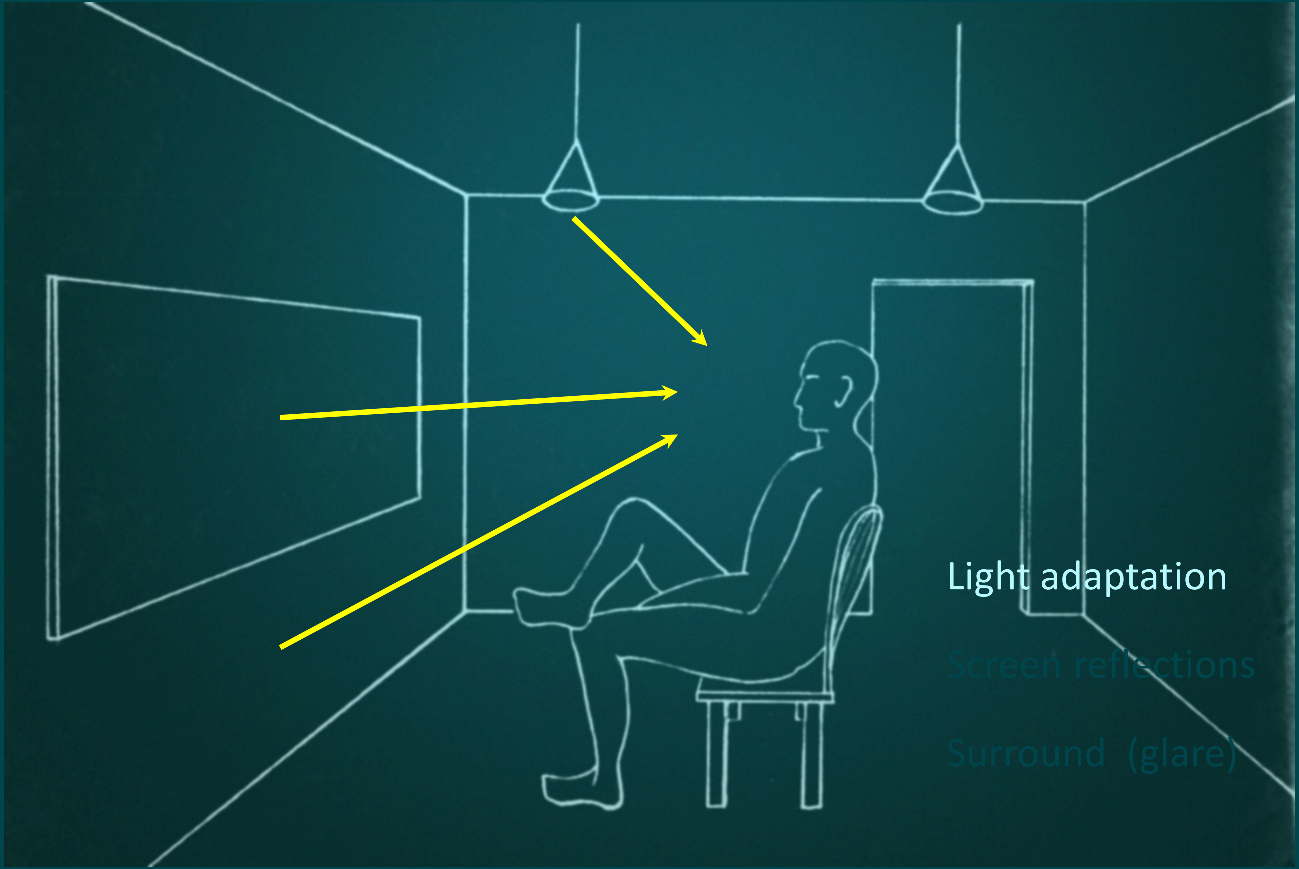
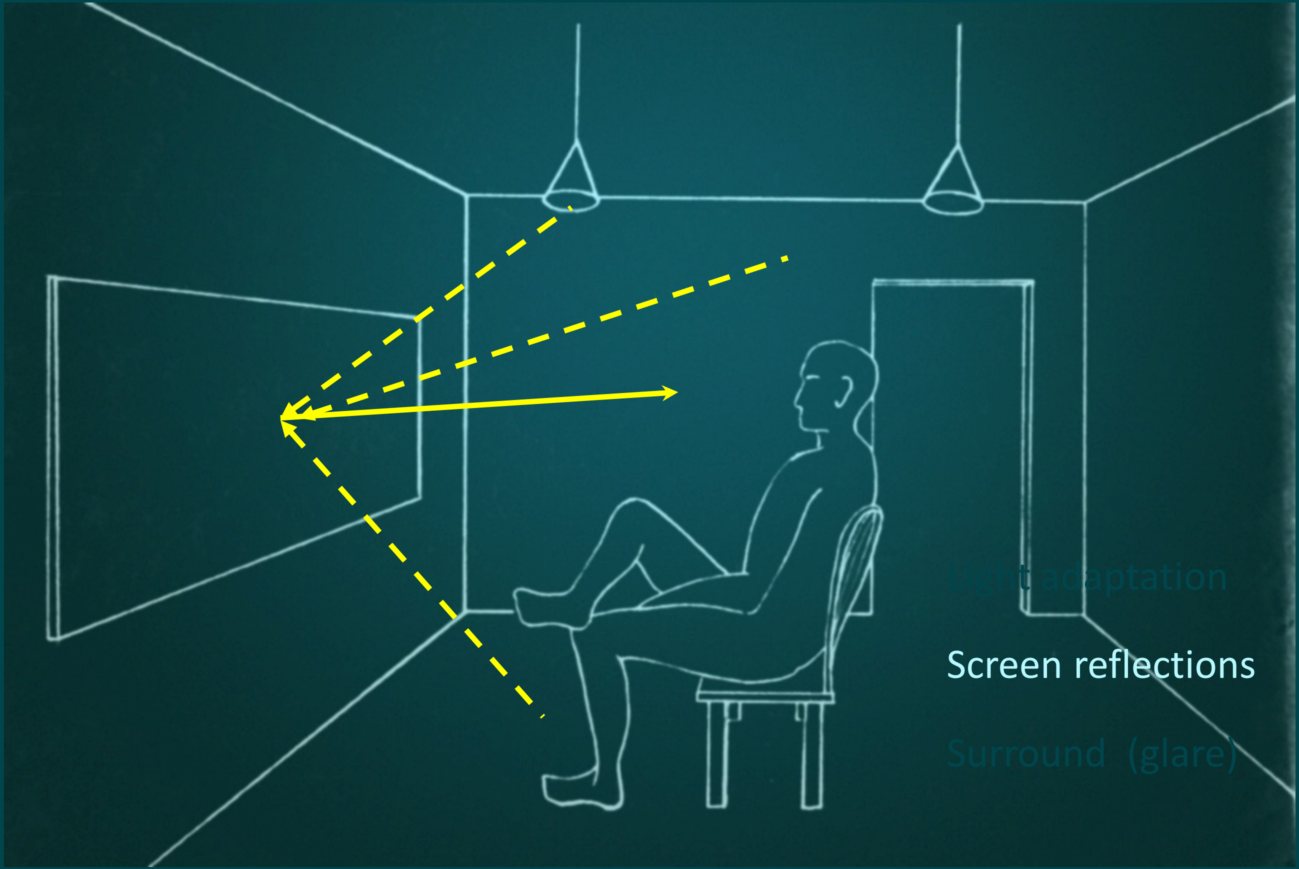
Key Effects of Ambient Light on Perceived Image



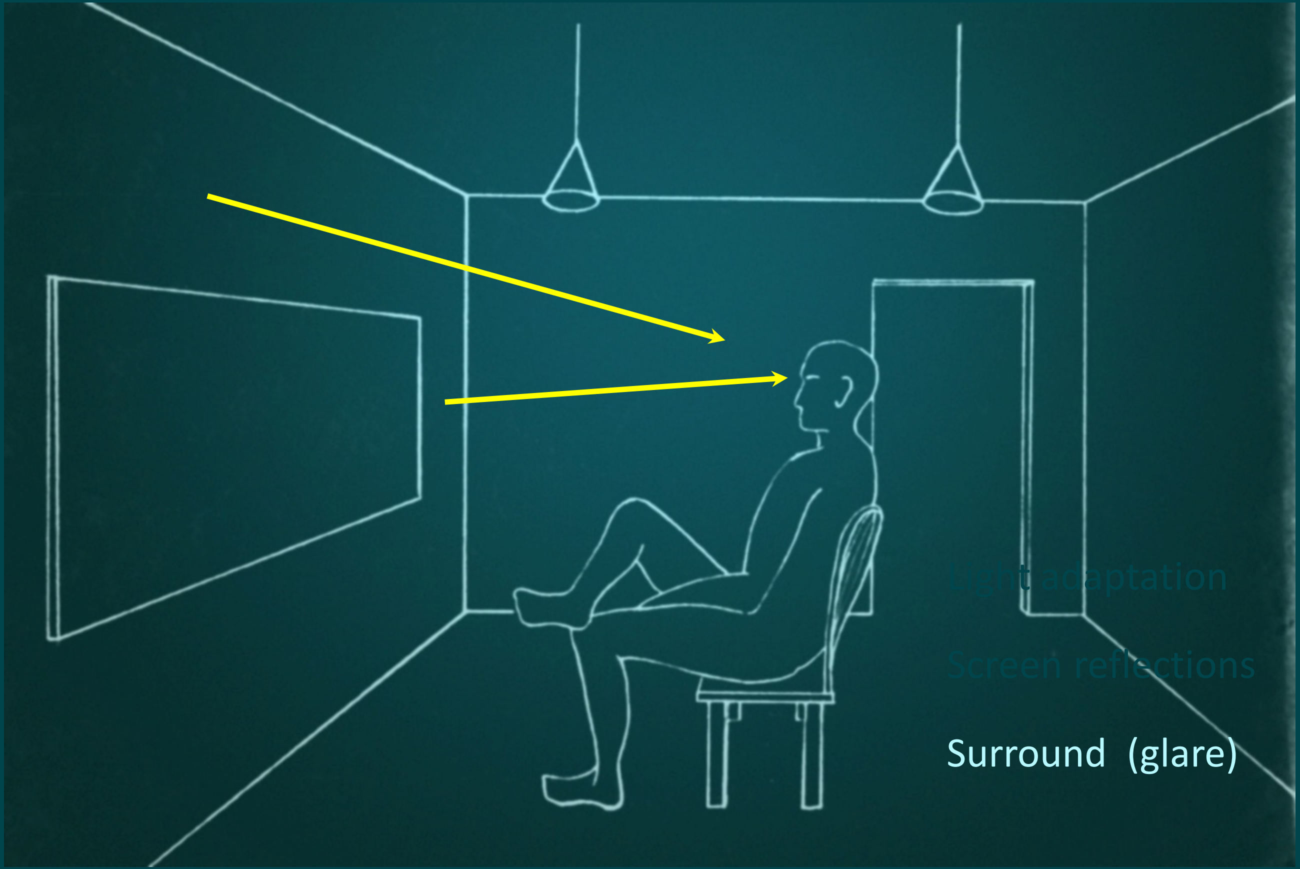
Key Effects of Ambient Light on Perceived Image



Key Effects of Ambient Light on Perceived Image



Key Effects of Ambient Light on Perceived Image



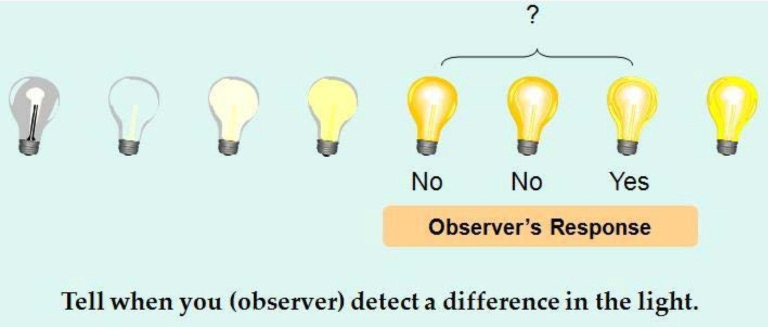
From Physics to Psychophysics

Detection threshold

- Lowest modulation in luminance that an average human can perceive
- Such an increase is a threshold, or a

  JND = just noticeable difference

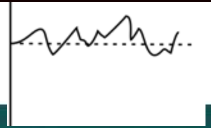
- Changes with luminance
- In vision science, signal contrast is often used to describe the difference



Weber Contrast

Michelson Contrast [redacted]

RMS Contrast



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Spatial Detection Basics

Classical Experiment (TVI)

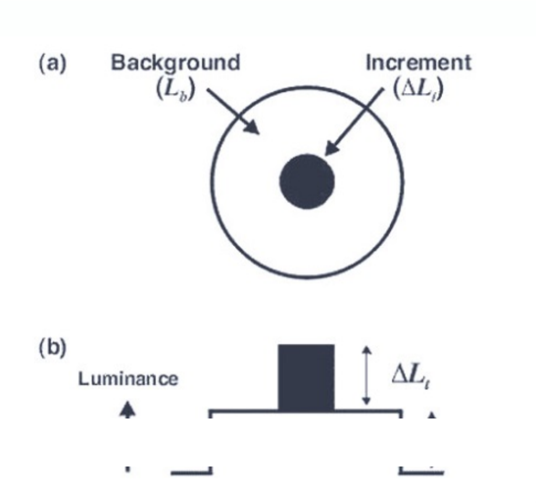
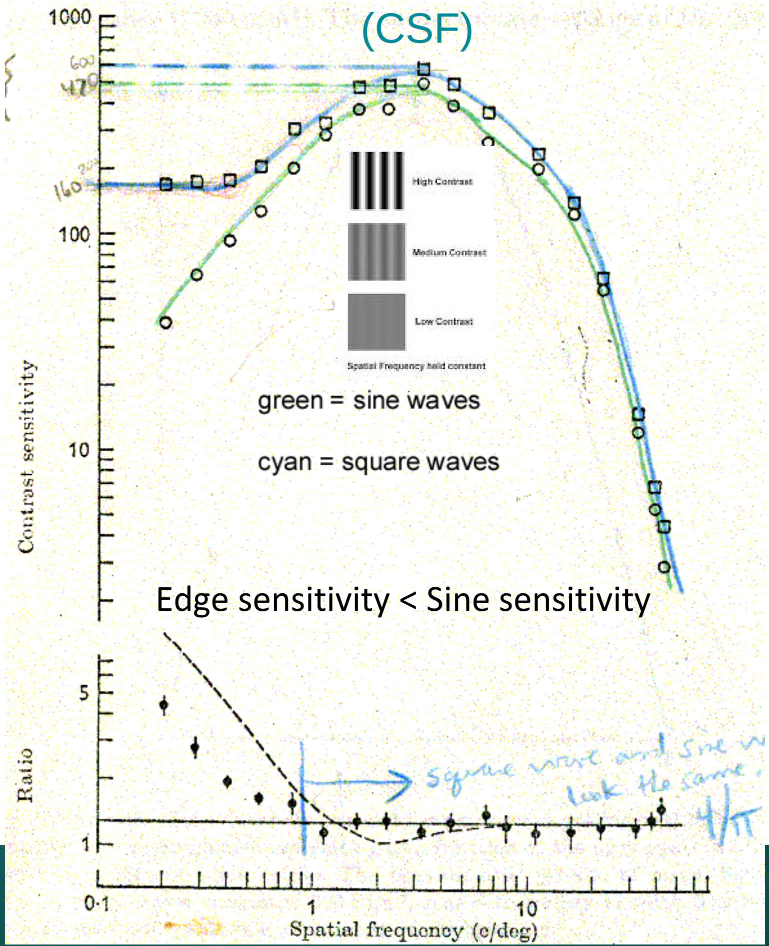


Figure 10. Light adaptation using an increment threshold experiment. (a) example of the stimulus used (b) luminance profile of the stimulus.

- Disc stimuli or split rectangle often used
- Both are dominated by 1/f spectrum of edge
- Step edges are not the best probe of HVS behavior
- HVS can see smaller amplitudes for sine waves

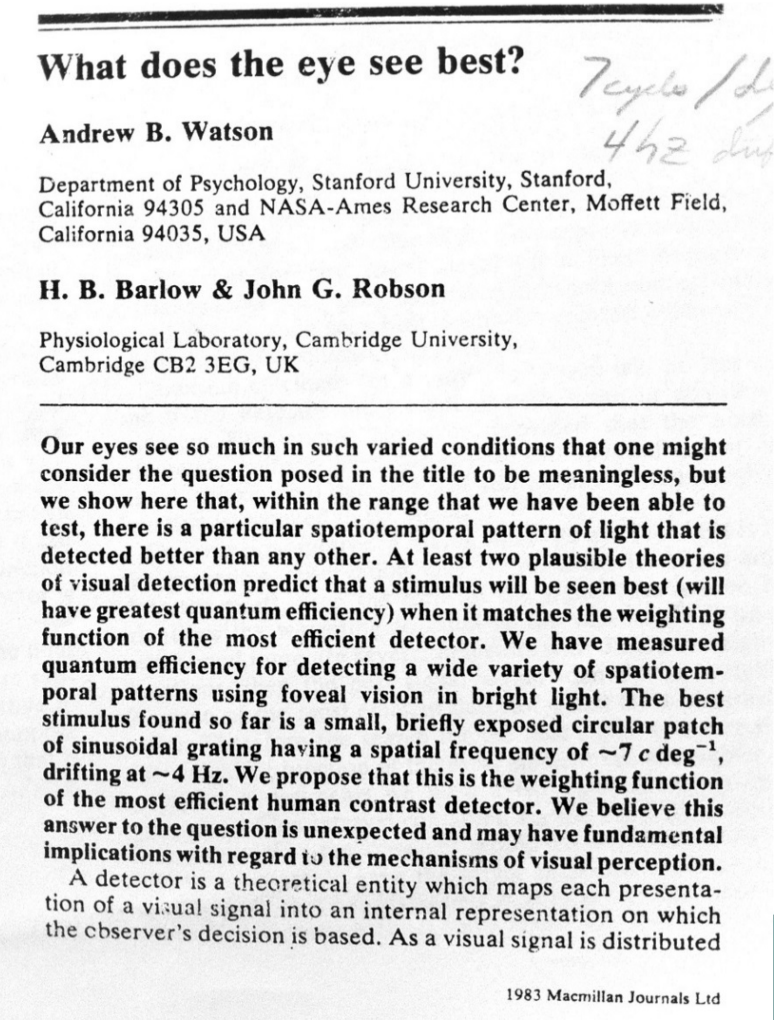
TVI = Threshold Vs. Intensity

Frequency Experiment (CSF)



Campbell and Robson ‘68 →

Spatial Detection Basics



What does the eye see best?

Andrew B. Watson

Department of Psychology, Stanford University, Stanford, California 94305 and NASA-Ames Research Center, Moffett Field, California 94035, USA

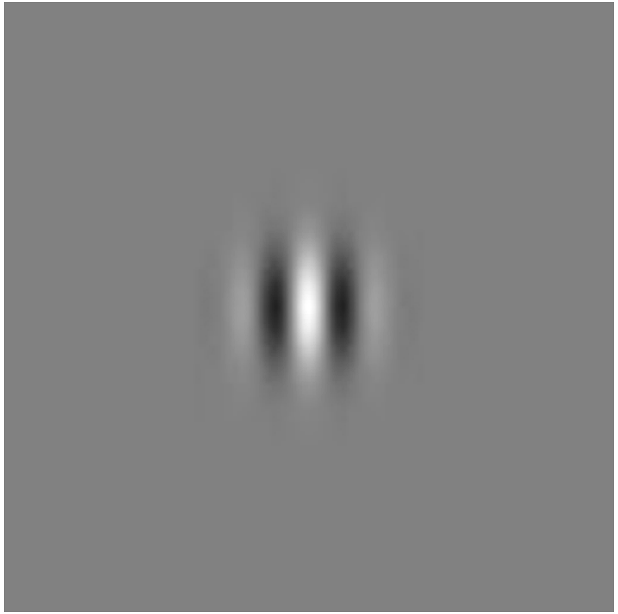
H. B. Barlow & John G. Robson

Physiological Laboratory, Cambridge University, Cambridge CB2 3EG, UK

Our eyes see so much in such varied conditions that one might consider the question posed in the title to be meaningless, but we show here that, within the range that we have been able to test, there is a particular spatiotemporal pattern of light that is detected better than any other. At least two plausible theories of visual detection predict that a stimulus will be seen best (will have greatest quantum efficiency) when it matches the weighting function of the most efficient detector. We have measured quantum efficiency for detecting a wide variety of spatiotemporal patterns using foveal vision in bright light. The best stimulus found so far is a small, briefly exposed circular patch of sinusoidal grating having a spatial frequency of ~7 $c\ deg^{-1}$, drifting at ~4 Hz. We propose that this is the weighting function of the most efficient human contrast detector. We believe this answer to the question is unexpected and may have fundamental implications with regard to the mechanisms of visual perception.

A detector is a theoretical entity which maps each presentation of a visual signal into an internal representation on which the observer's decision is based. As a visual signal is distributed

1983 Macmillan Journals Ltd



Gabor Stimuli

Effects of Surround

New Experiment: Equipment and Configurations

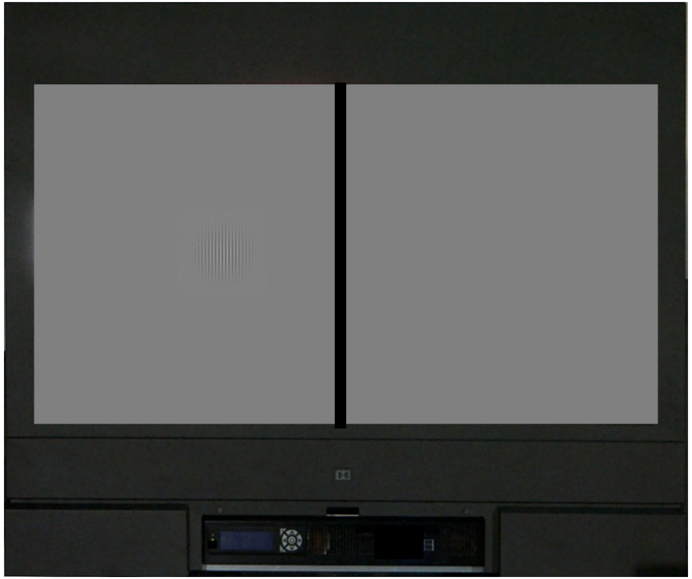
- Pulsar Display
  - 1.0 ND sheet placed over display
  - lowers black level to 0.*0005* cd/m^2

- Surround was white wall illuminated to:

  0.4
  5.
  10.
  20.
  100. all in cd/m^2 (nits)

- Viewer does not see light source
- No direct incident light on display surface


Observer


entire display behind 1.0 ND filter
to get lower than display capability

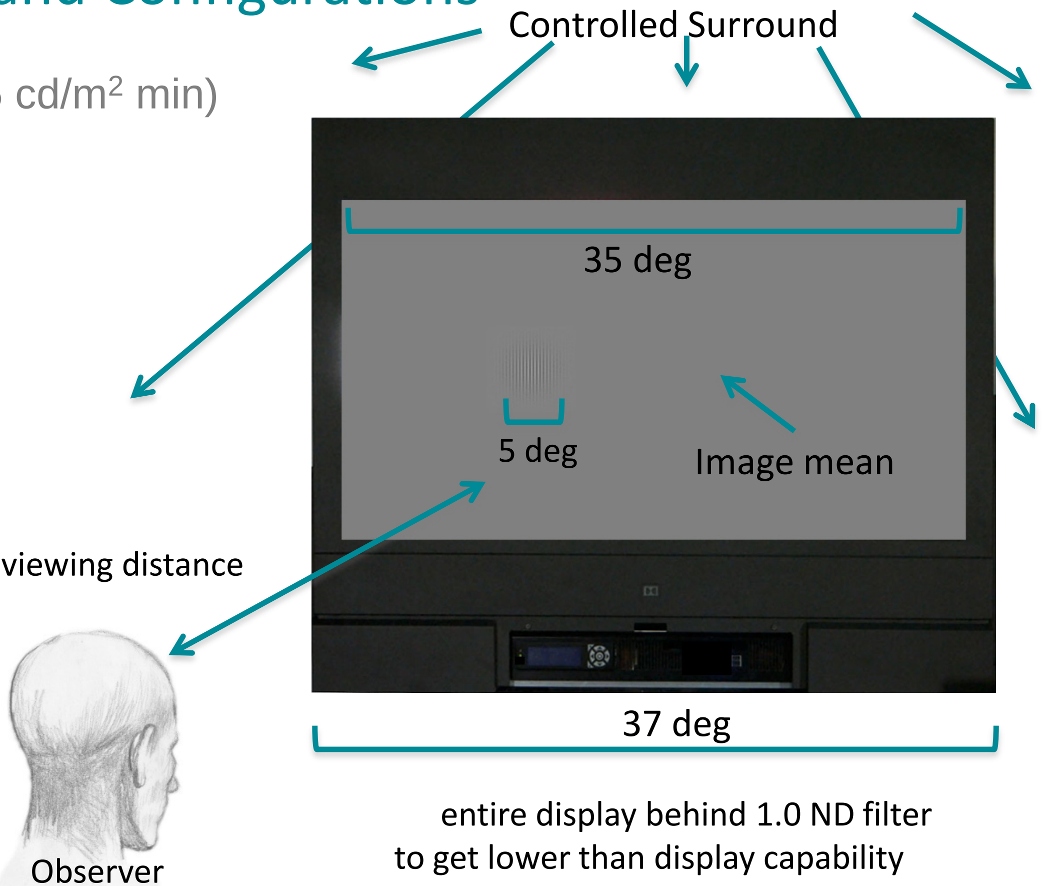
New Experiment: Equipment and Configurations

- Pulsar Display (1920x1080, 12 bits, 0.005 cd/m^2 min)
  - 1.0 ND sheet placed over display
  - lowers black level to 0.*0005* cd/m^2

- Surround was white wall illuminated to:

  0.4
  5.
  10.
  20.
  100. all in cd/m^2

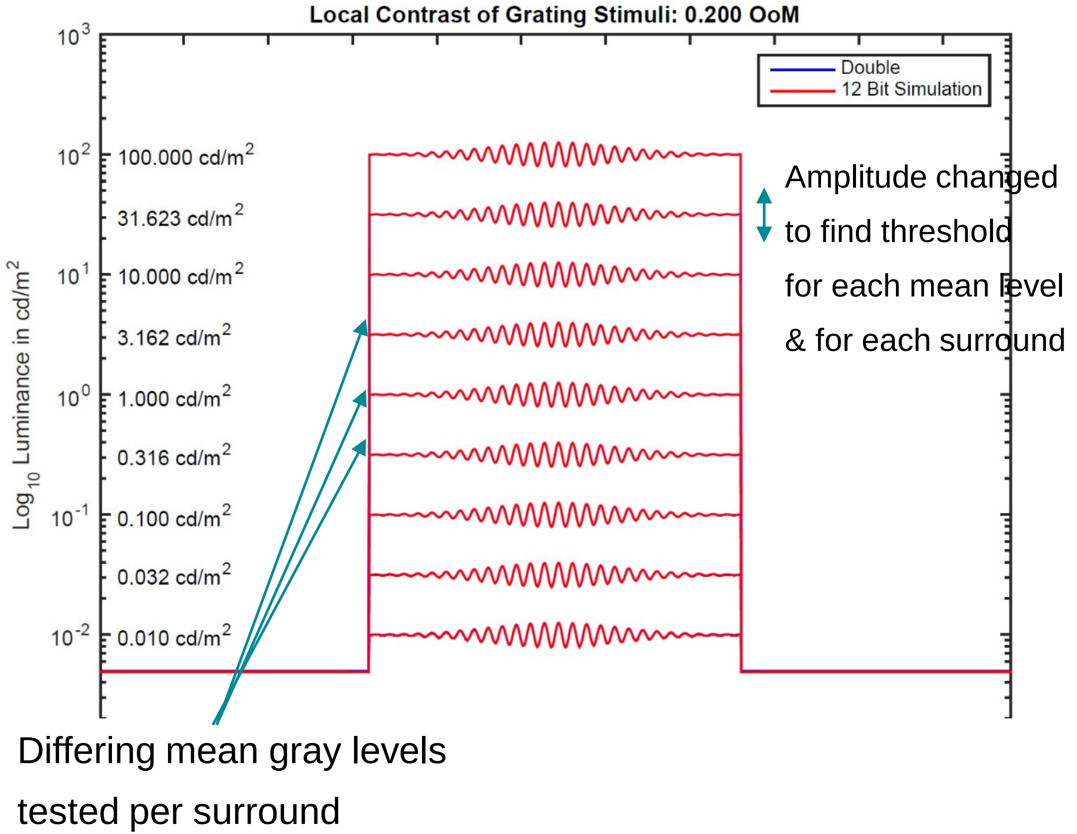
- Surround luminance is key variable
- Image (signal) mean lum level also varied
- 25 subjects



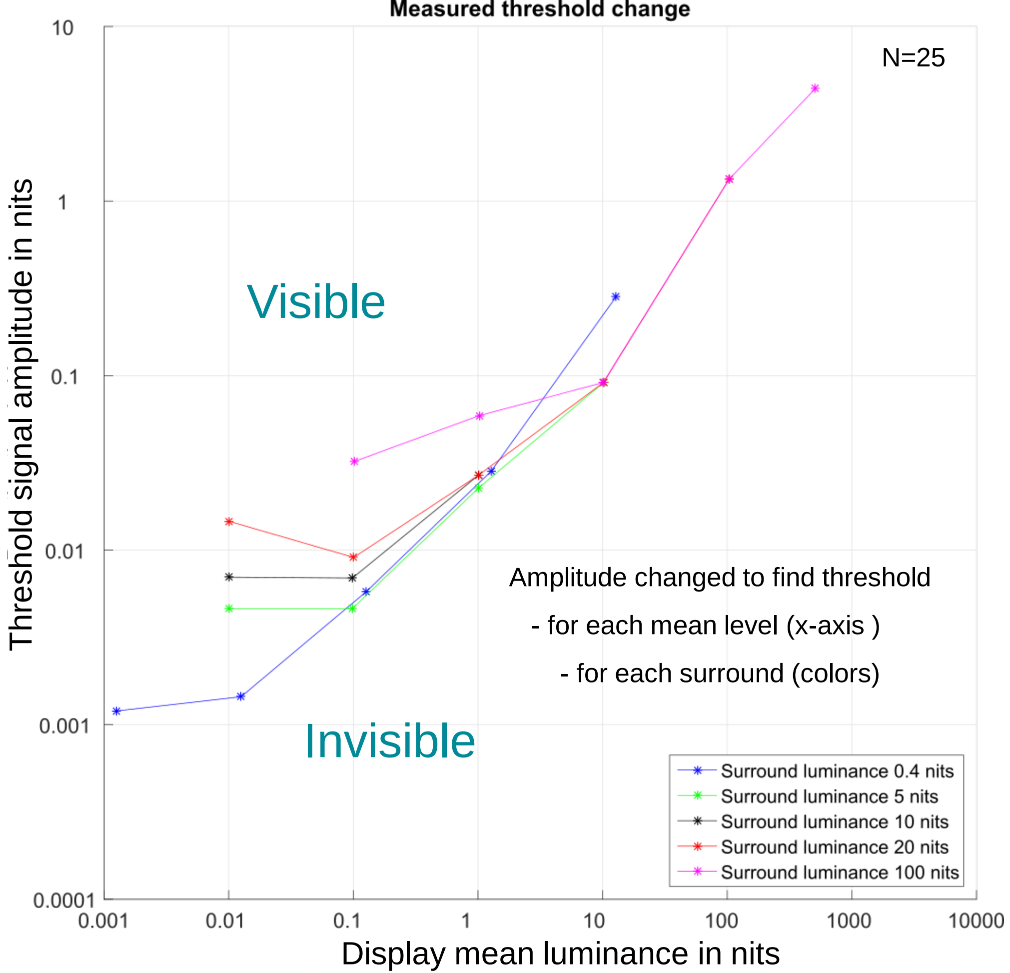
New Experiment: Stimulus and task details

- Gabor Stimulus, 1cy/deg, 5 deg
- For each surround:
  - Threshold as a function of mean gray level was measured
- Threshold obtained by 2AFC
- Subject task:
  - Indicate which half of screen (L or R) had Gabor (or, was not uniform)

Experiment performed at EPFL

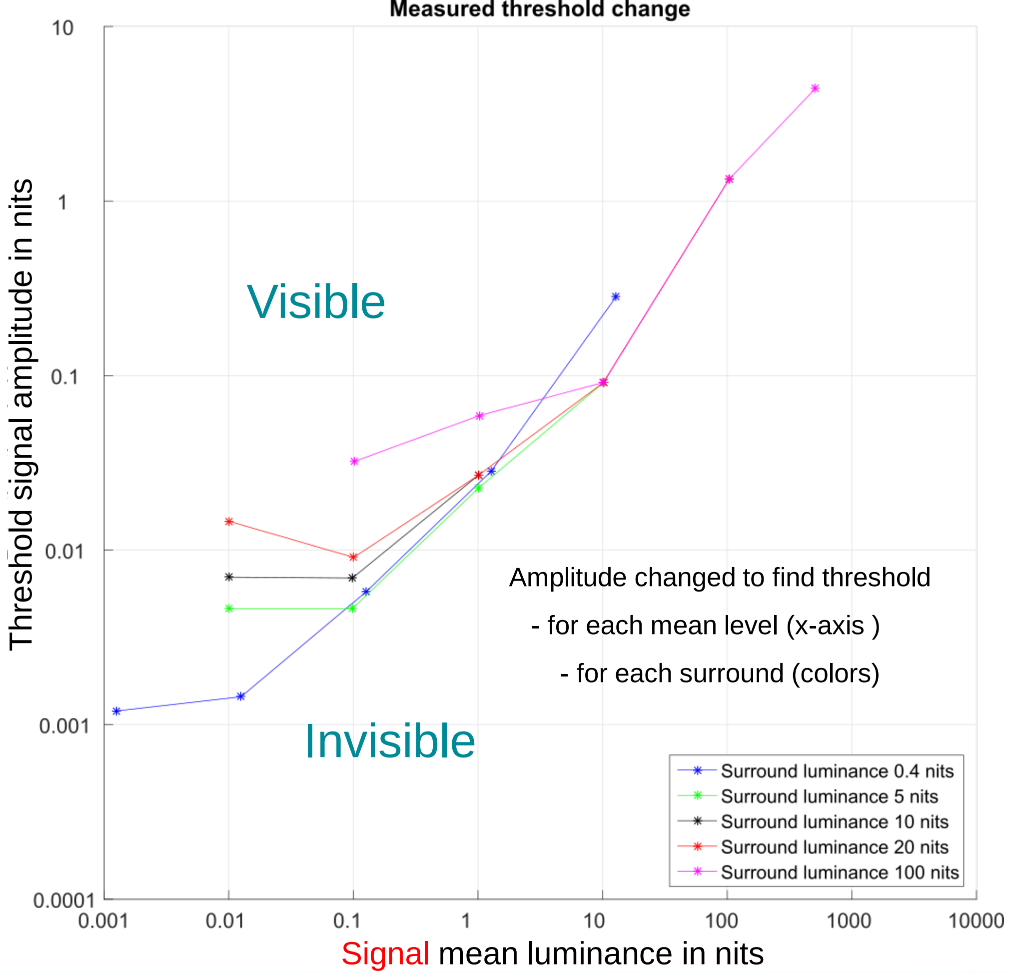


Results



Note: Threshold plotted in Δ luminance, not Michelson contrast

Results



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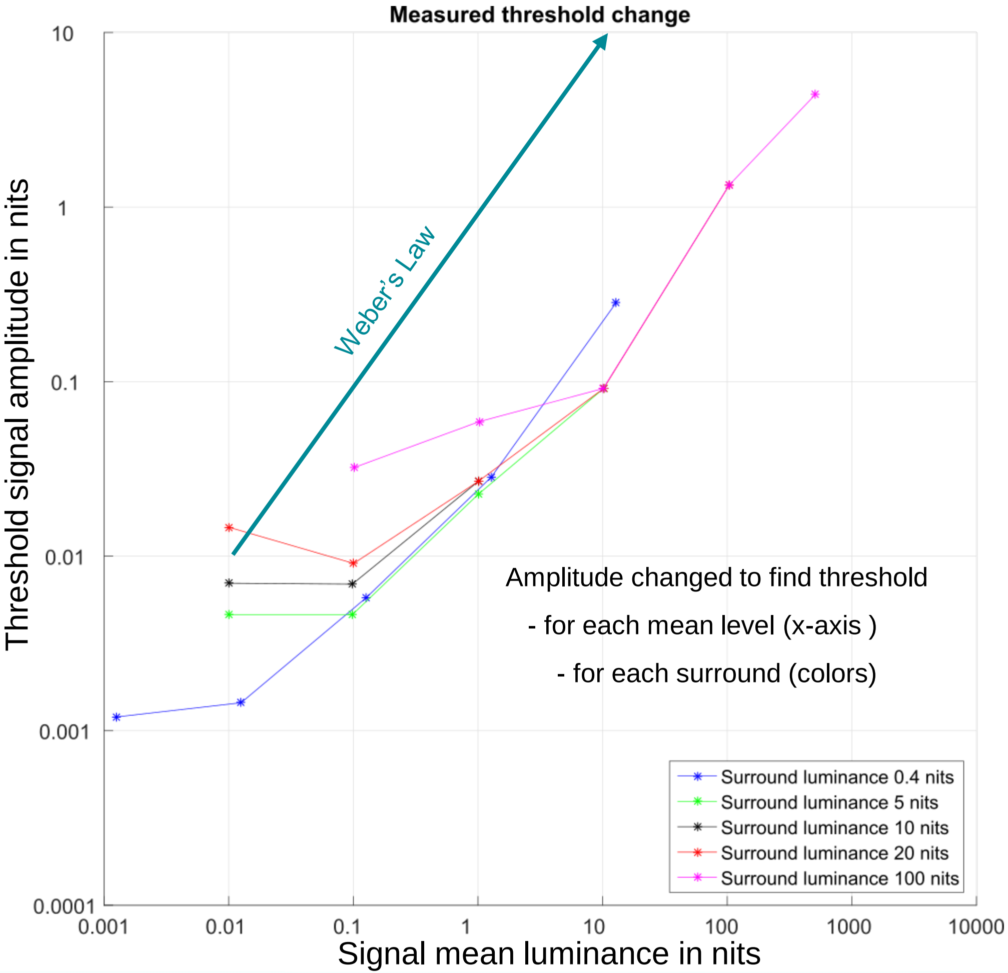
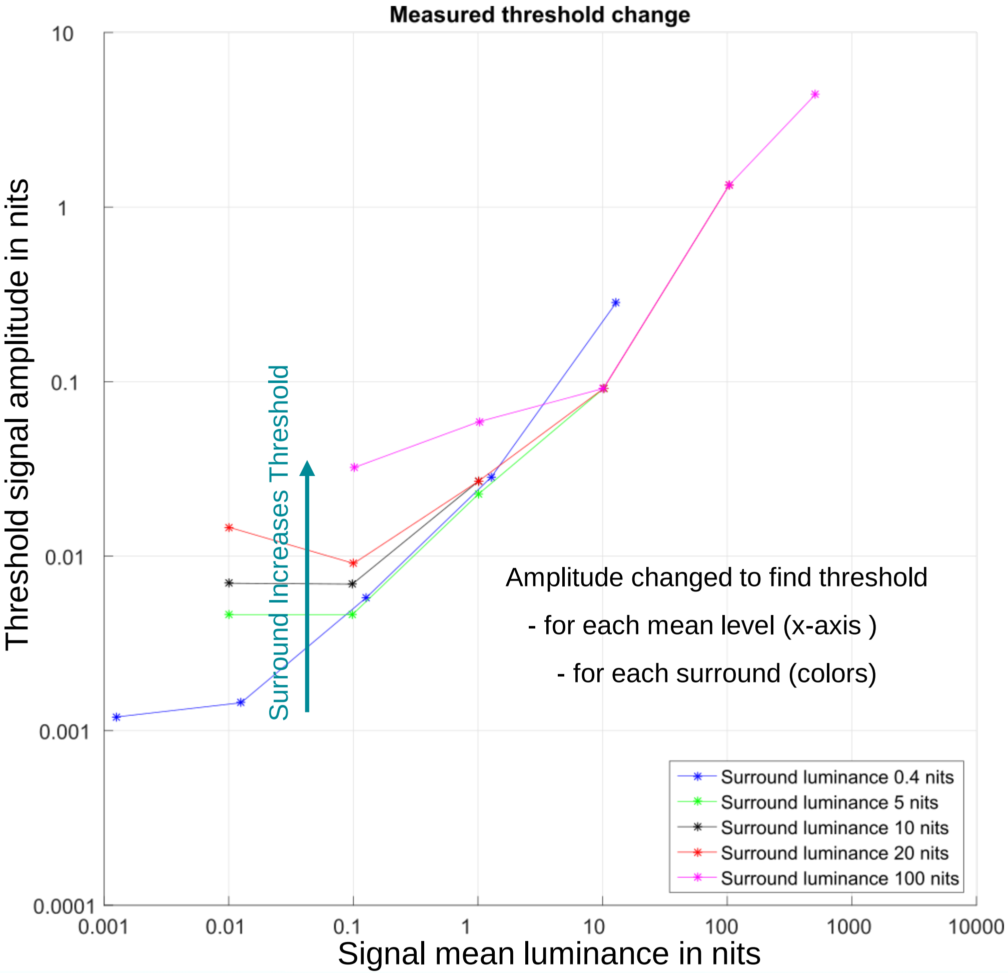
Results

- Detection thresholds increase with increasing mean luminance



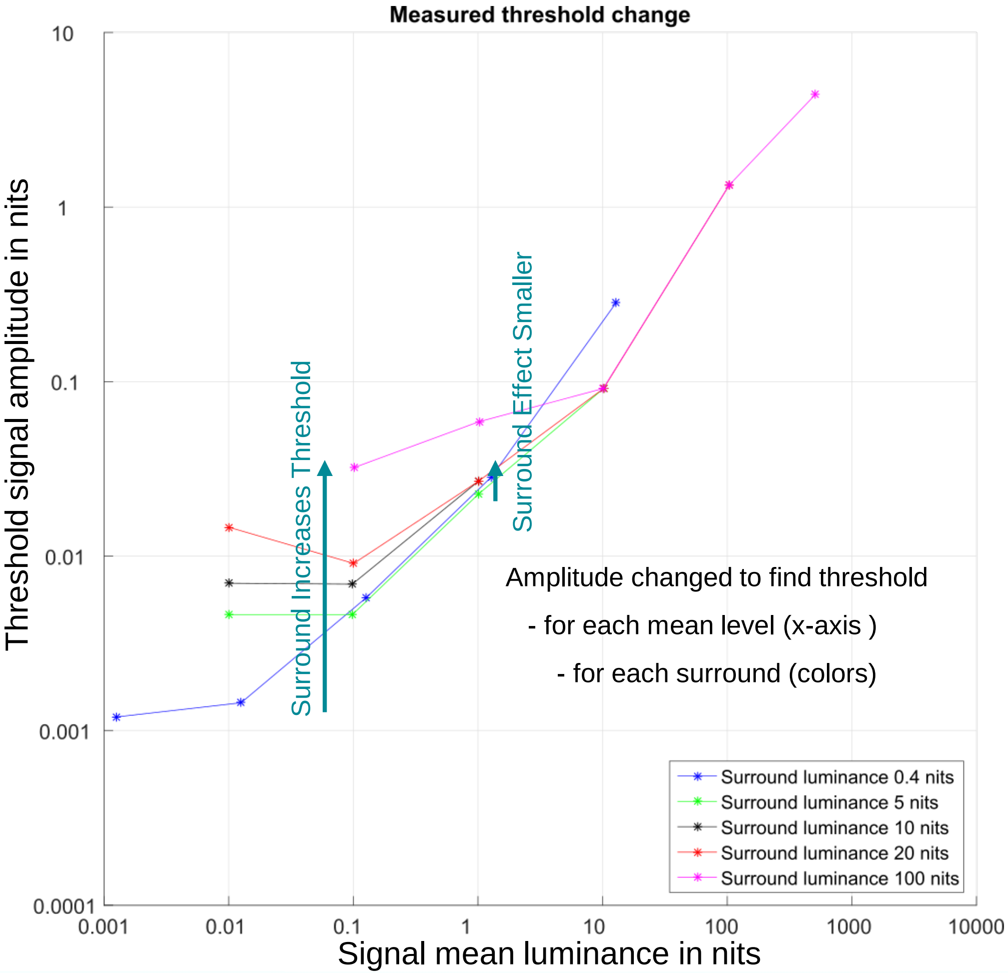
Results

- Detection thresholds increase with increasing mean luminance
- Detection thresholds increase with increasing surround luminance



Results

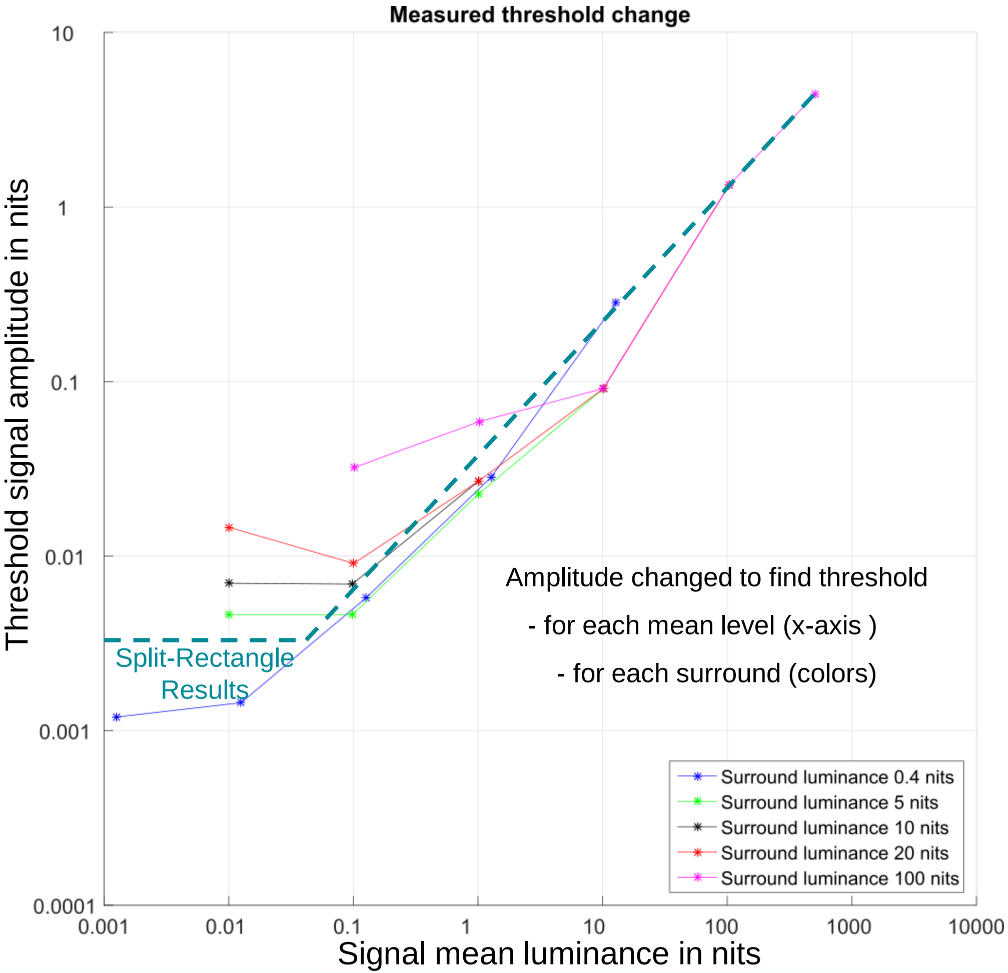
- Detection thresholds increase with increasing mean luminance
- Detection thresholds increase with increasing surround luminance
  - But mainly for lower luminances



Results

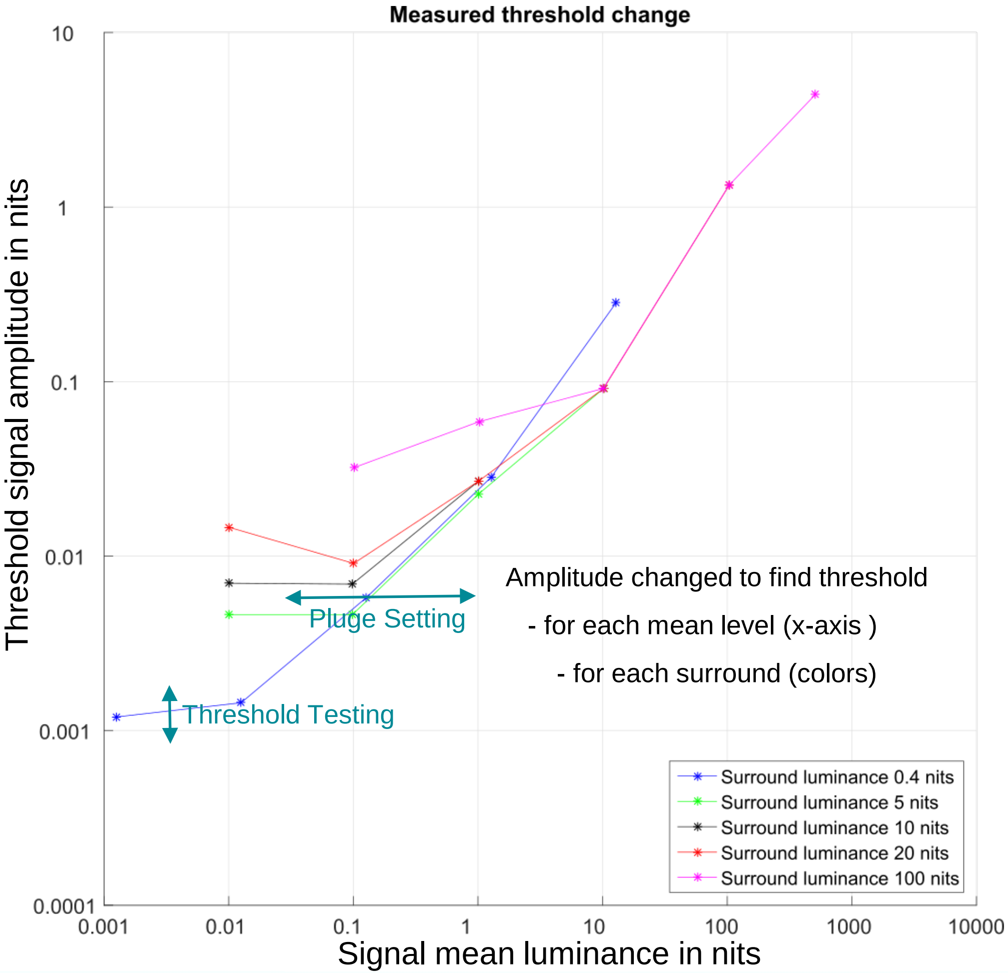
- Detection thresholds increase with increasing mean luminance
- Detection thresholds increase with increasing surround luminance
  - But mainly for lower luminances
- Similar to split-rectangle Black Level experiment by Mantiuk 2010, but better visibility at lower luminances :
  - 0.001 vs. 0.0035 cd/m2

    (frequency) vs (edge)



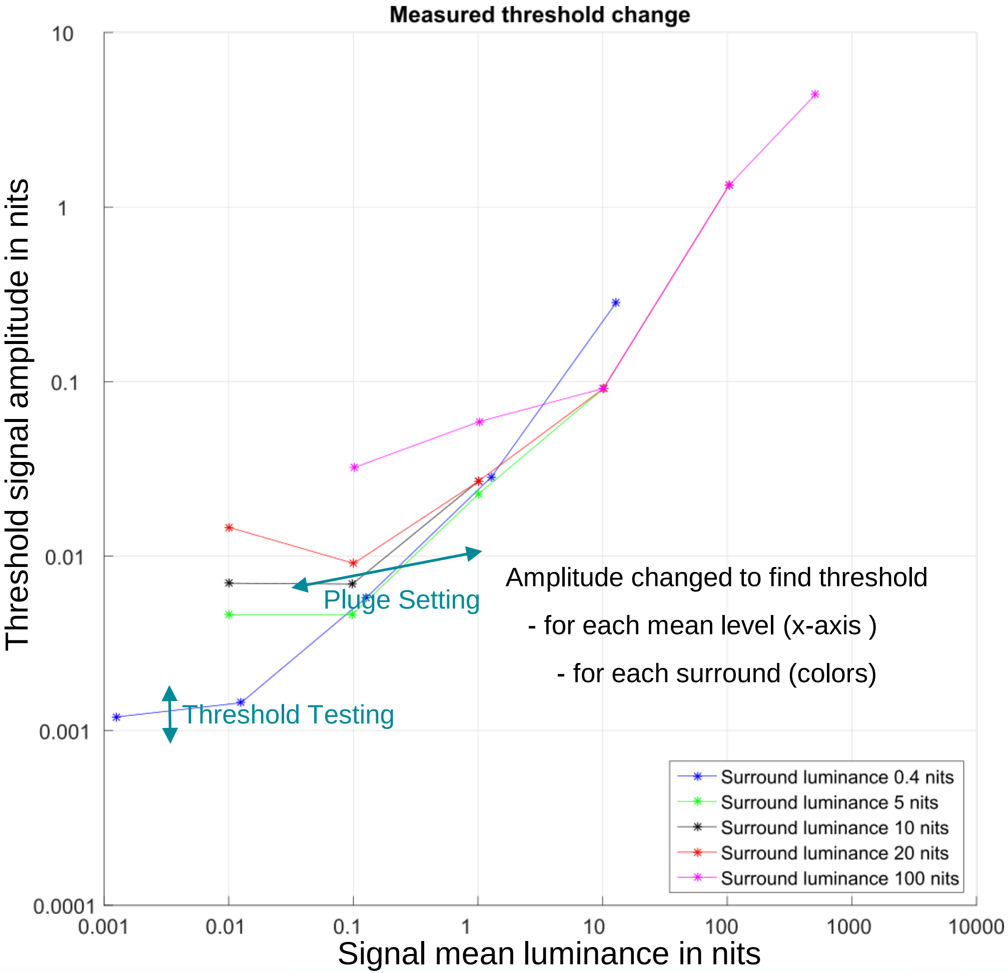
Familiarity w/ Pluge

- Pluge is a quick method for adjustment in the field
- For a given surround, adjusts a contrast signal amplitude's 'mean' level until it reaches threshold



Familiarity w/ Pluge

- Pluge is a quick method for adjustment in the field
- For a given surround, adjusts a contrast signal amplitude's 'mean' level until it reaches threshold
- Pluge adjustment is usually in gamma domain, so signal amplitude in Δ luminance changes
  - Also Michelson contrast not constant
  - Mean level also changes
- Pluge not intended to understand HVS
- HVS Threshold method too time consuming for field work



Effect of surround light on detection thresholds

- Measured in a ONR* report

  [Rogers, Carel 1973]

- Depends on pattern size and ratio of surround and pattern luminance

- Whittle's crispening effect:

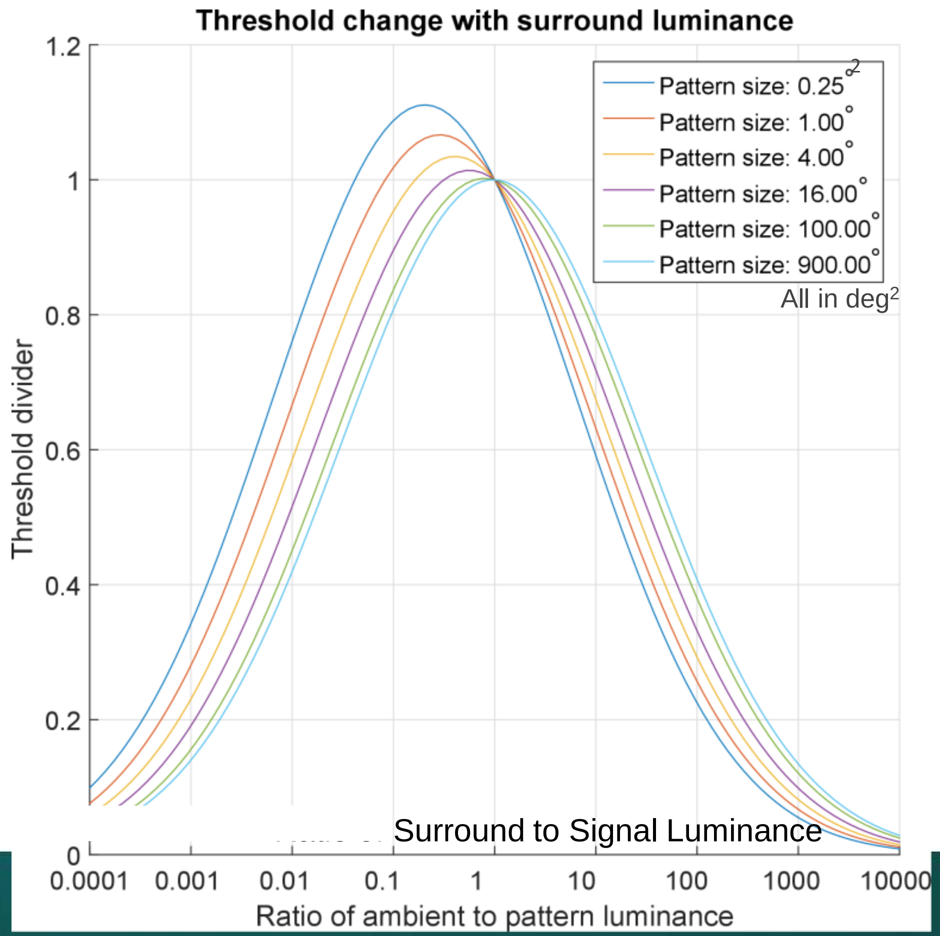
  Thresholds lowest when surround equals the signal mean

  (except for very small patterns)

- Pattern size = Display FOV

- Surround = Wall behind display

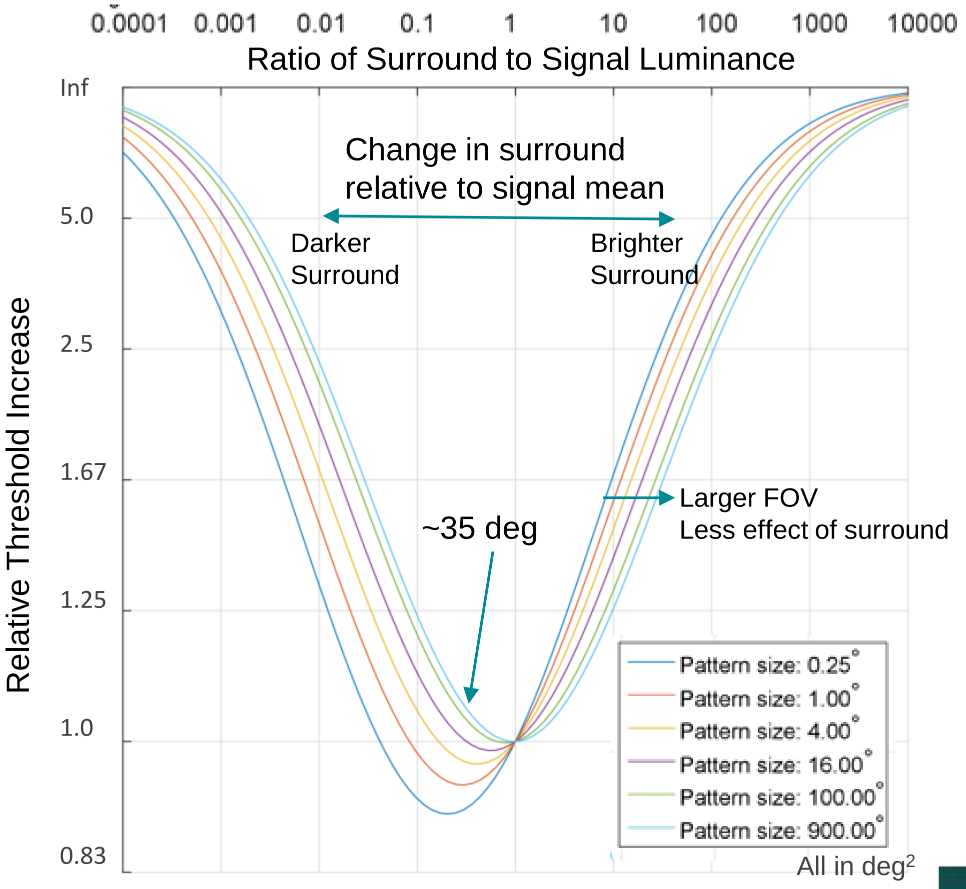
- Also modelled by Barten



*Office of Naval Research

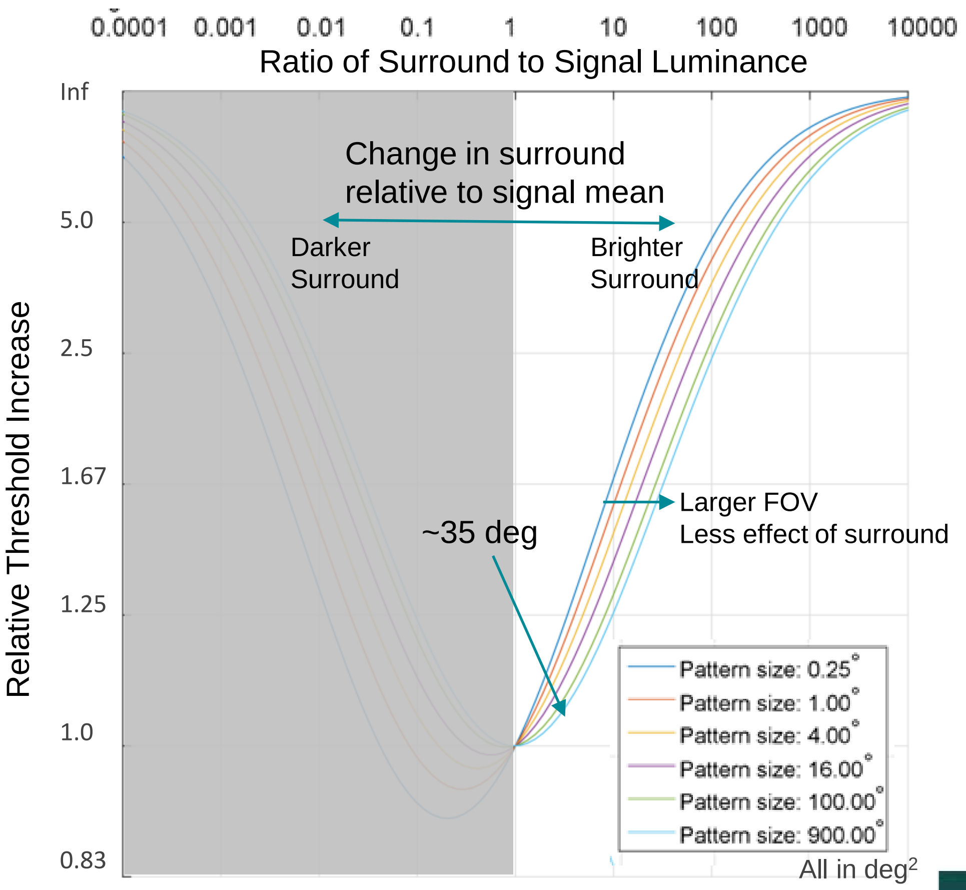
Effect of surround light on detection thresholds

- Model based on Rogers and Carol
- Inverted so y-axis is threshold increase due to the surround

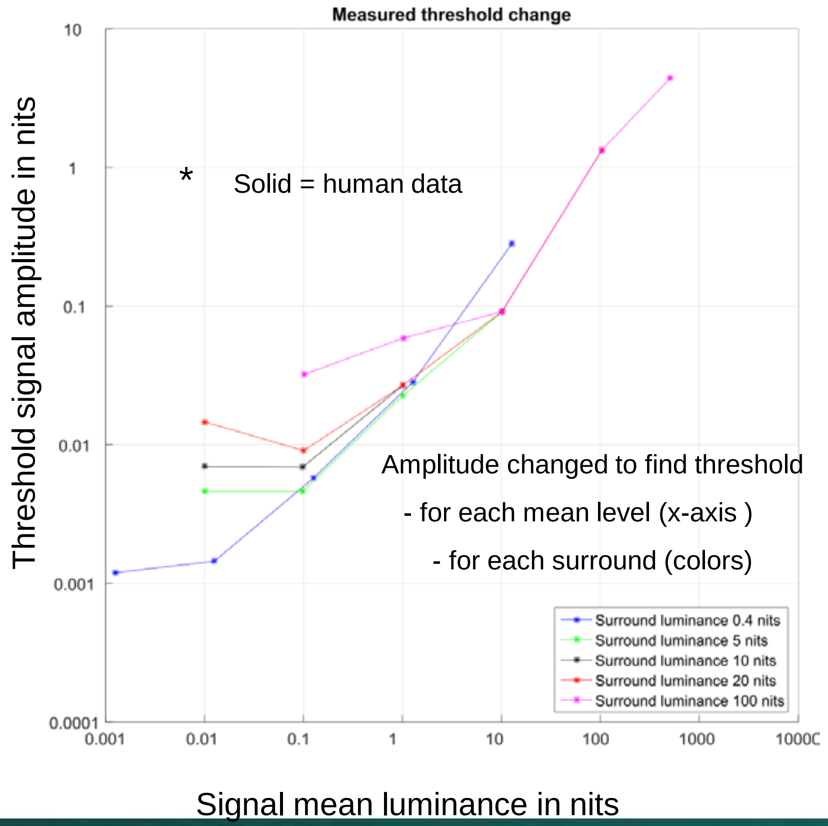


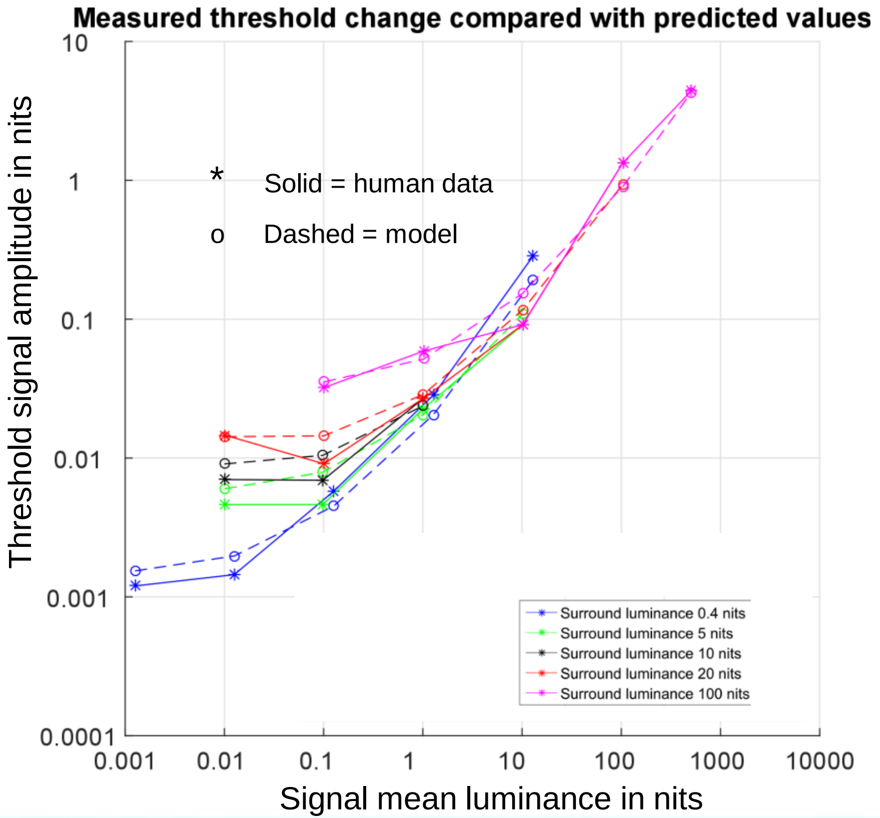
Effect of surround light on detection thresholds

- Model based on Rogers and Carol
- Surrounds greater than display levels are more relevant for ambient applications
- Note : Data for surrounds darker than display have less confidence



How well can model predict measurements?





Black Level Psychophysical Study

Conclusions

- Black level visibility lower for Gabors than edge-based stimuli (discs, patches, pluge)
- Increasing surround luminance raises all thresholds, but raises black level thresholds more
- Black level detail as low as 0.001 nits can be seen in dark surround with 35 FOV display
- Black level < 0.01 nit visible for 5nit surround
  - For 35 deg FOV (3H)
  - Expected to be lower for larger FOV (e.g., 1.5H for UHD resolution or cinema)
- Model based on Rogers and Carol surround data predicted our essential results

- Important not to confuse black level visibility with preference of aesthetic appearance of black (which may be even lower)

Entropy vs Sensation

Whether to determine display's black level from information or aesthetics?

- Entropy criteria: *Information* most important → Shadow detail (Pluge & Gabor)
- Sensation criteria: *Appearance* of black level most important → Aesthetics & Intent

Current work

- Accounts for surround effect only

Future work

- Display reflectivity effect needs modelled and verified
- Adaptation to room/environment needs to be considered
  - Dependence on Field of View
  - Larger FOV: adaptation to display
  - Adaptation to room/environment stronger for small FOV applications
- Use a better adaptation model based on scene content
  - Eg. Van Gorp and Mantiuk 2015

Related Work

- Eda, Koike, Matsushima, Ayama (Utsunomiya U) EI 2008: Effect of blackness level on visual impression of images
  - Studied boundaries of Beginning of Black and Really Black (BB and RB)
  - Preference of BB black level lower for visual artists than engineers by 7-10 Code values in gamma (SDR calibrated)
  - Preference of RB black level similar for both groups (<0.01 nits, ambient illuminance 13 lux)
- Mantiuk, Daly, Kerofksy (Sharp), EI 2010: The luminance of pure black: exploring the effect of surround
  - Used split-field rectangle , studied varying small FOVs (<6 deg)
  - Found min visible black level of 0.0035 nits
- Daly, Kunkel, Sun, Farrell, Crum (Dolby), SID 2013: Black level preferences for cinema and home TV
  - CDFs (cumulative distribution functions) , dark ambient
  - 0.0043 to satisfy 90% of viewers for home TV (26" TV, 3H)
  - 0.002 To satisfy 90% of viewers for cinema (16' screen, 1.5H)
- Vyvey, Castellar, Maes, Vandevelde (Barco) PQS 2016: **Perceived intra-frame dynamic range in cinema environs**
  - Glare effect limited to ~16 deg (ICDM)
  - Black level of 0.005
- Richards et al (Dolby) SMPTE 2017: Physical black level dependencies on secondary screen illumination
  - Importance of inter-frame ADL, average displayed luminance (aka, APL)
  - Black levels of 0.000017 in screening rooms, and 0.001 for well-designed PLF theaters, with HDR projector on (ICDM cornerbox)

Appendix

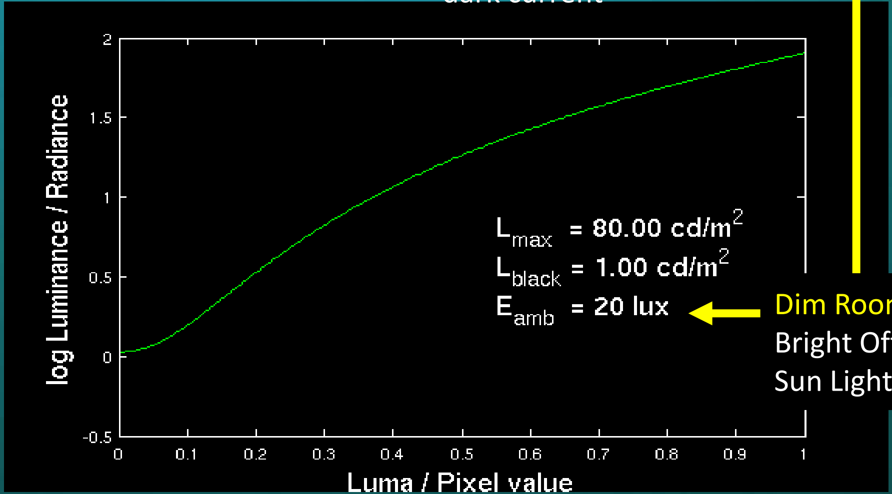
Display Reflectivity
&
Black Level Elevation

Display Model :

Gamma — Gain — Screen reflections

$$L_d(L') = (L')^{\gamma} \cdot (L_{max} - L_{black}) + L_{black} + \frac{k}{\pi} E_{amb}$$

Luminance — Luma — Modulation Black level 'dark current'



Dim Room
Bright Office
Sun Light

Display Model

Gamma

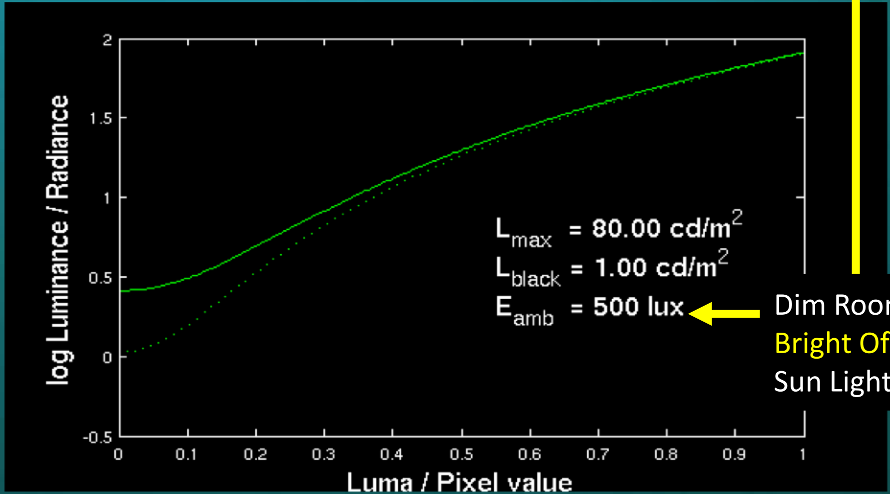
Gain

Screen reflections

$$L_d(L') = (L')^{\gamma} \cdot (L_{max} - L_{black}) + L_{black} + \frac{k}{\pi} E_{amb}$$

Luminance

Luma



Dim Room

Bright Office

Sun Light

Display Model

Gamma — Gain — Screen reflections

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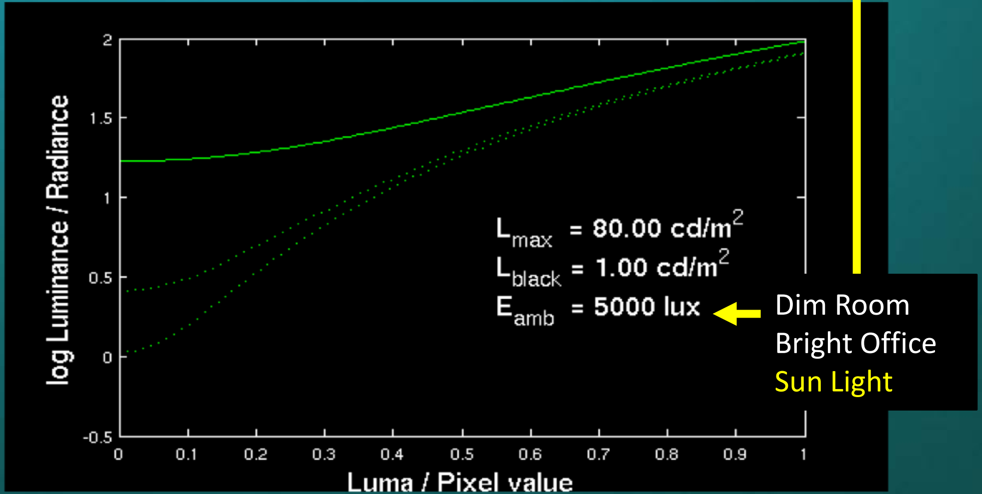
Luminance — Luma



Confidence intervals

Plotted in Delta luminance on log axis