16th Annual International Radiance Workshop

A Validated Approach to Predicting Visibility +

Designing Visually Accessible Spaces
NIH Grant 2 ROI EY017835-06A1

Rob Shakespeare
Indiana University PI

Other research team members from:
University of Minnesota, Low Vision Lab & Computational Vision
University of Utah, Computer Science & Visual Perception & Spatial Cognition

Increased awareness

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None identify potential visual hazards during the design process…

This is the DEVA Goal… here is our update.

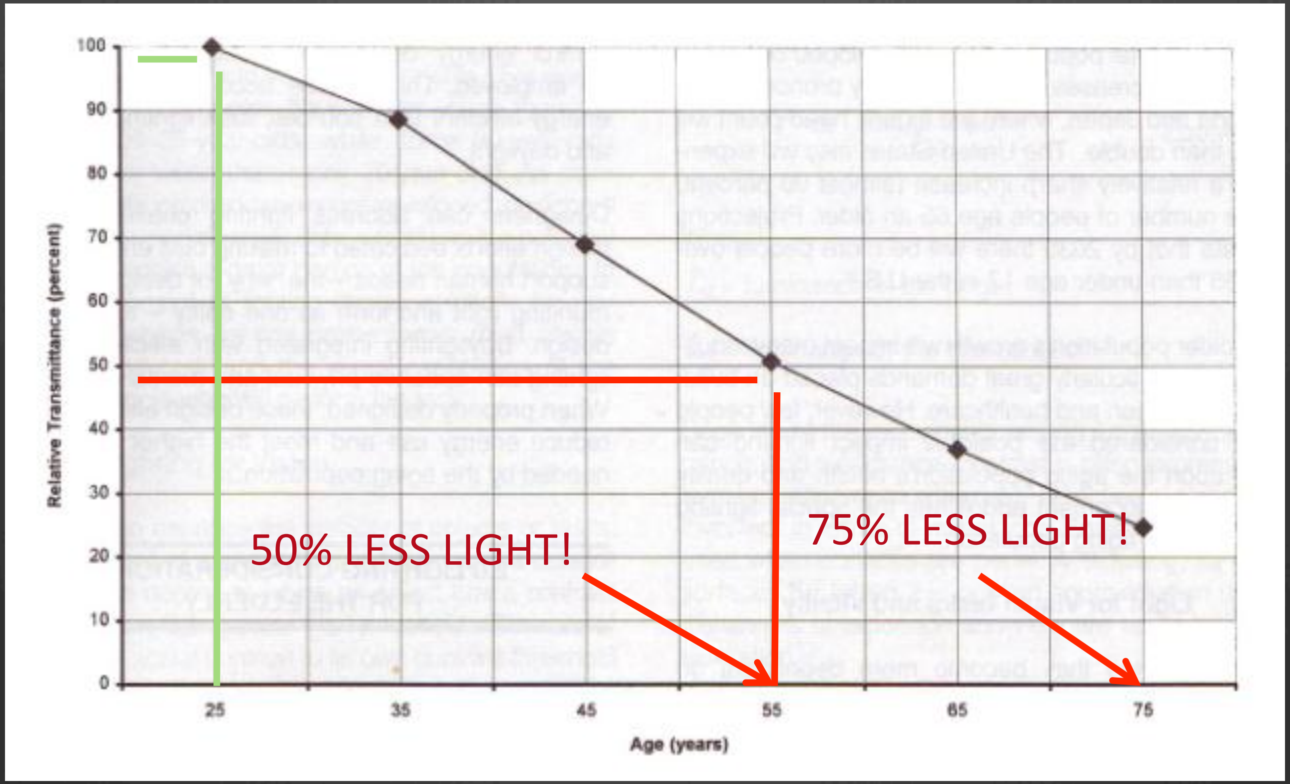
DEVA Overview

A tool that identifies mobility hazards during the architectural design phase (uses HDR image data)

A tool that assists in evaluating the implemented design, and which can be used to assist in evaluating existing environments for mobility hazards

The integration of these tools into the architect's work-flow to provide the missing link between general guidelines and the successful visual accessibility of a project.

Ageing alone moves each of us towards decreased visual function

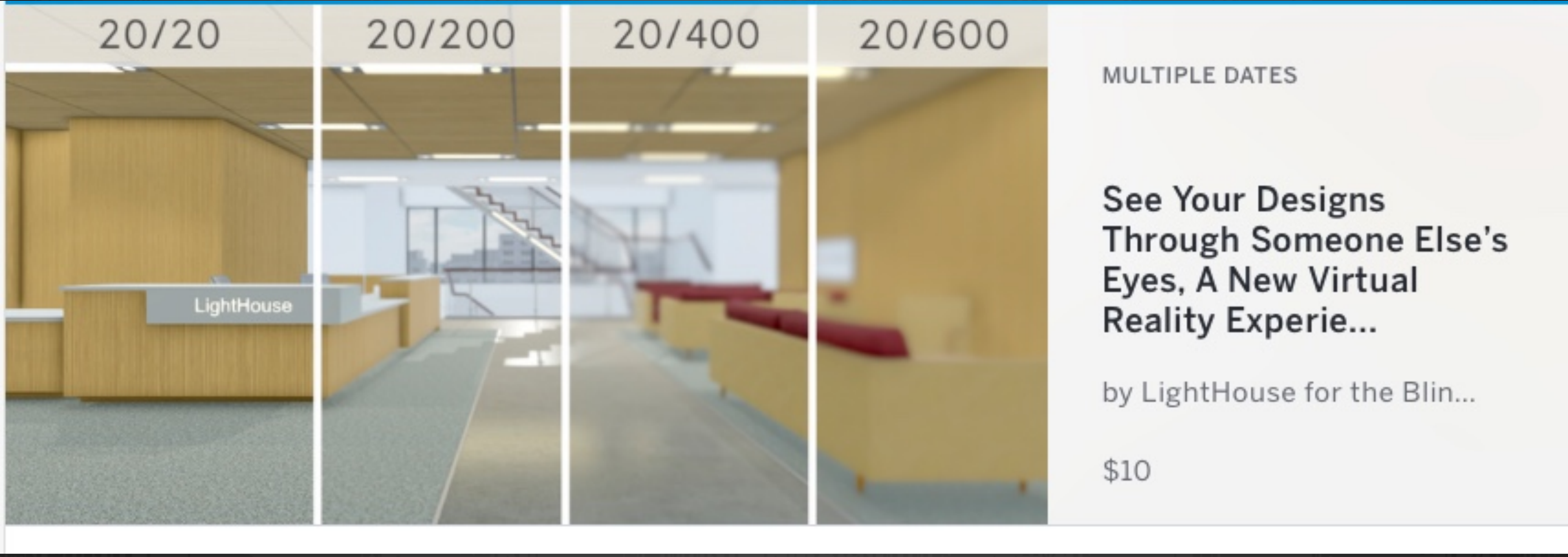


(Image derived from ANSI/IES RP-28-07)

– As people age, total light transmittance decreases (the pupil gets smaller and reduces the amount of light entering the eye)
– Scattering and attendant glare sensitivity also increases

A reminder that NO-ONE ESCAPES

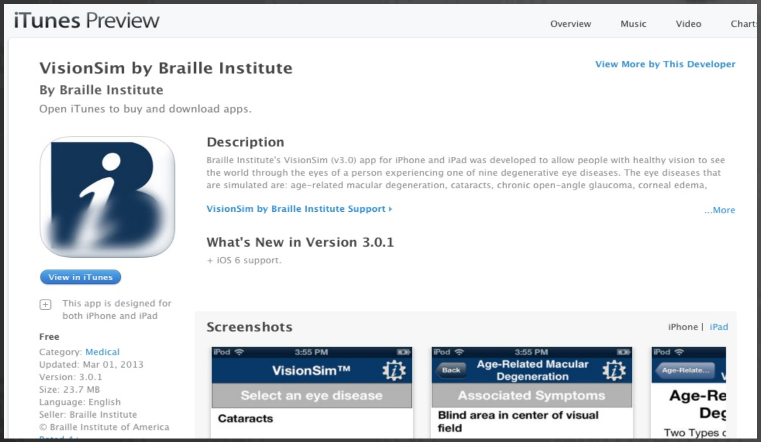
Increasing awareness

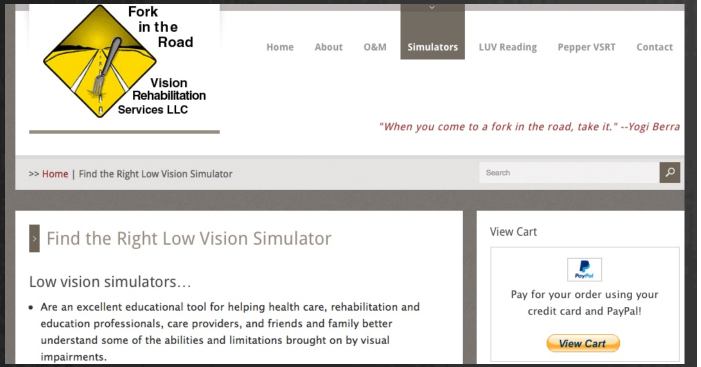


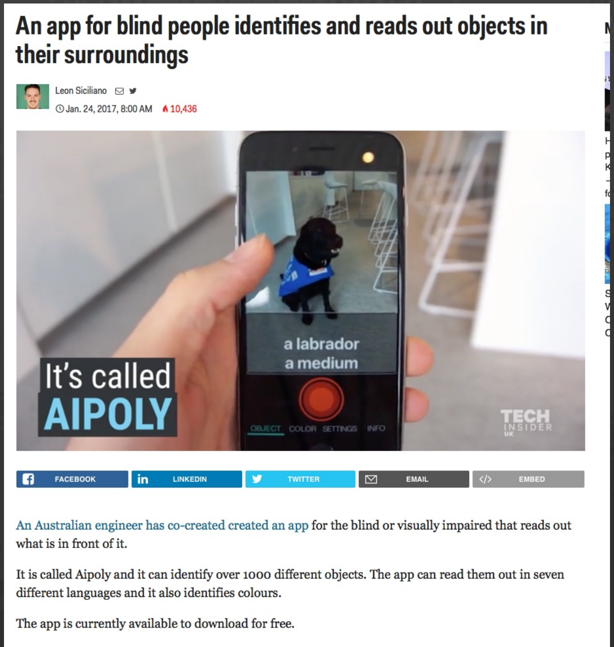
"From the subtle, gauzy effects of cataracts to the more dramatic challenges of tunnel vision… changes in vision are incredible hard to convey in words… Fully sighted designers can guess, but rarely know how to optimize their products for low vision"

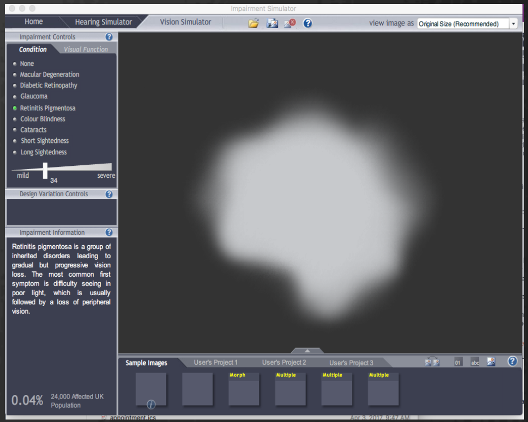
- *Theia Immersive*

Increasing awareness









many more ….

Increasing awareness

AIA sessions

Designing Supportive Environments for People with Low Vision

Session #14
Friday, October 16, 2015
1 LU/HSW

DESIGNING FOR LOW VISION

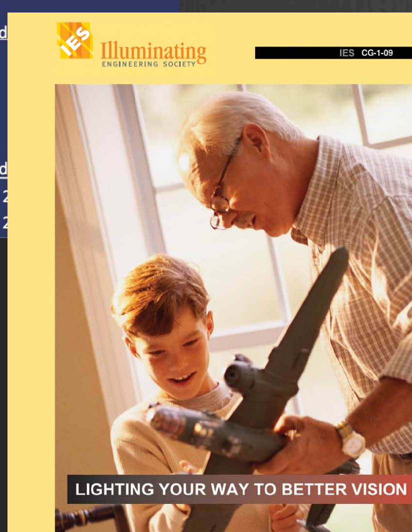
ASHRAE/IES 90.1 - 2016

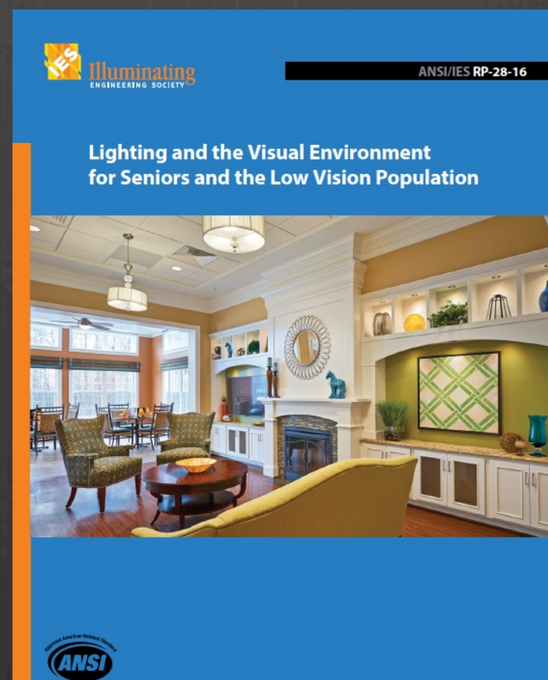
Higher LPD's provided for Visually Impaired:

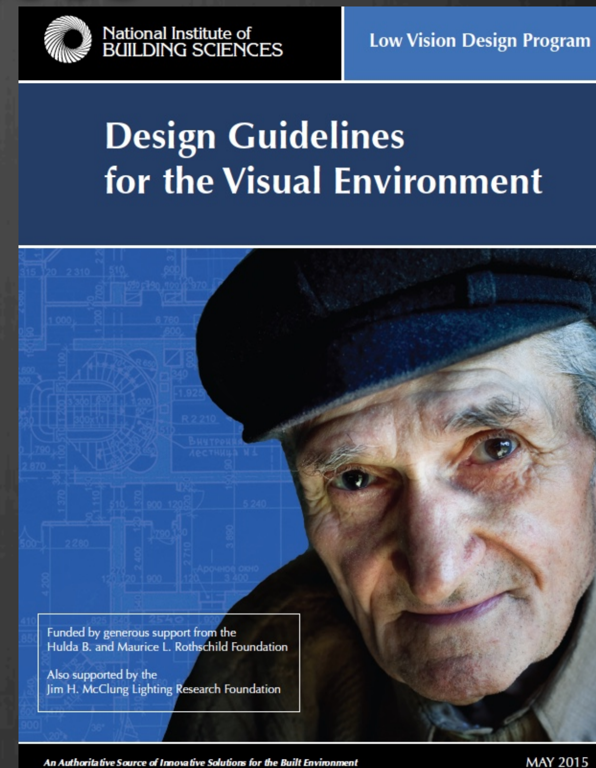
Table 9.6.1 (Pages 95 – 99)

Space type:	Typical	Visually impaired
Dining/Activity Areas:	.65	2.65
Corridors:	.66	.92
Lobbies:	.90	1.80
Restrooms:	.98	1.21

Building Type	Typical	Visually Impaired
Living Room/Recreation:	.73	2
Chapel	1.53	2







Design Guidelines…

Acuity Conversion Chart… so many UNITS!

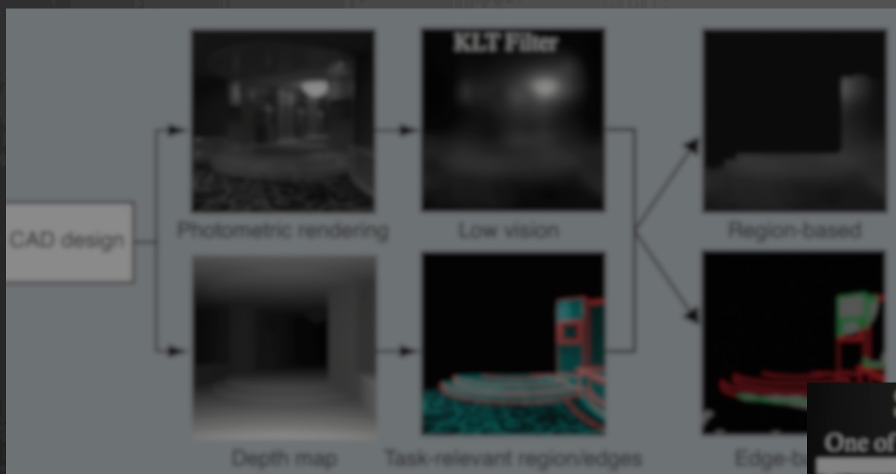
Distance visual acuity conversion table

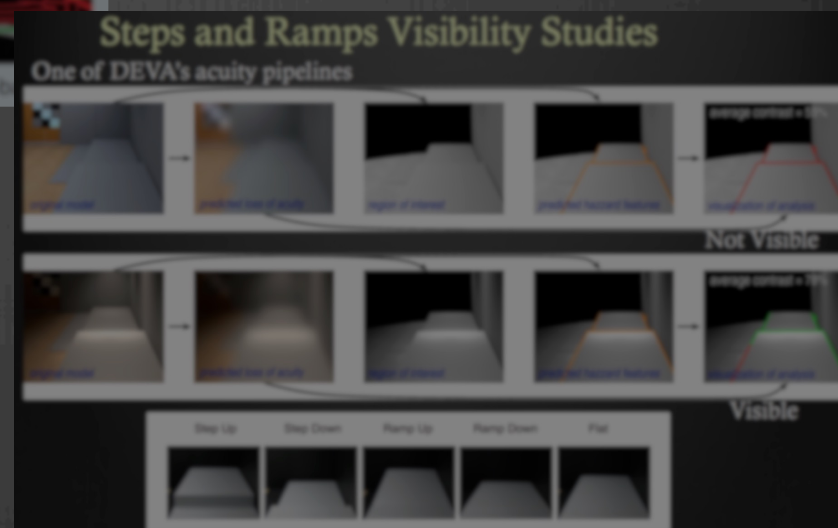
MAR*	LogMAR	VAR	Snellen (metric)	Snellen (imperial)	Decimal*
0.50	–0.30	115	6/3	20/10	2.0
0.63	–0.20	110	6/3.8	20/12.5	1.60
0.80	–0.10	105	6/4.8	20/16	1.25
1.00	0.00	100	6/6	20/20	1.00
1.25	0.10	95	6/7.5	20/25	0.80
1.60	0.20	90	6/9.5	20/32	0.63
2.0	0.30	85	6/12	20/40	0.50
2.5	0.40	80	6/15	20/50	0.40
3.2	0.50	75	6/19	20/63	0.32
4.0	0.60	70	6/24	20/80	0.25
5.0	0.70	65	6/30	20/100	0.20
6.3	0.80	60	6/38	20/125	0.16
8.0	0.90	55	6/48	20/160	0.125
10.0	1.00	50	6/60	20/200	0.10
20	1.30	35	6/120	20/400	0.05
100	2.00	0	6/600	20/2000	0.01

Legal Blindness: 20/200 or less with best possible correction

MAR, minimum angle of resolution; VAR, visual acuity rating.

Many explorations, simulations, and human studies have lead to this current iteration.. perhaps the final pipeline!



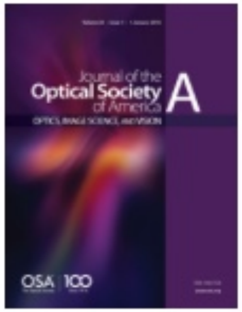


A Validated Approach to **Predicting Visibility**

https://www.osapublishing.org/josaa/abstract.cfm?uri=josaa-34-4-583

Simulating visibility under reduced acuity and contrast sensitivity

William B. Thompson, Gordon E. Legge, Daniel J. Kersten, Robert A. Shakespeare, and Quan Lei



Vol. 34, Issue 4, pp. 583-593 (2017) • https://doi.org/10.1364/JOSAA.34.000583

The key contribution is the development of a way to parameterize the simulation using standard clinical measures of acuity and contrast sensitivity.

For the gory details, please read the paper….

$$S_l(f_l)=\begin{cases} SP_l-(f_l-FP_l)^2w_L^2 & \text{if } f<FP \\ SP_l-(f_l-FP_l)^2w_H^2 & \text{if } f\geq FP \end{cases} \quad (1)$$

where:

- S = contrast sensitivity
- $S_l = \log_{10}(S)$
- f = spatial frequency
- $f_l = \log_{10}(f)$
- SP = peak contrast sensitivity
- $SP_l = \log_{10}(SP)$
- FP = frequency of peak contrast sensitivity
- $FP_l = \log_{10}(FP)$
- w_L = constant for low frequency portion of CSF
- w_H = constant for high frequency portion of CSF.

left-right/top-down sliding, we re-parameterize Equation 1 by replacing SP by $c \times SPN$ and FP by $a \times FPN$:

$$S_l(f_l)=\begin{cases} SPN_l+log_{10}c-(f_l-FPN_l-log_{10}a)^2w_L^2 & \text{if } f<a\times FPN \\ SPN_l+log_{10}c-(f_l-FPN_l-log_{10}a)^2w_H^2 & \text{if } f\geq a\times FPN \end{cases} \quad (2)$$

where:

- SPN = peak normal vision contrast sensitivity
- $SPN_l = \log_{10}(SPN)$
- FPN = frequency of peak normal vision contrast sensitivity
- $FPN_l = \log_{10}(FPN)$

FP, can be found by solving the equation

$$SPN_l+log_{10}c-(FP_l-FC_l)^2w_H^2=0 \quad (11)$$

for FP_l. This yields:

$$FP_l=FC_l-\frac{(log_{10}(c)+SPN_l)^{\frac{1}{2}}}{w_H} \quad (12)$$

An explanation of the approach in laymen's terms..

Our approach builds on the work of Eli Peli, who described a method for transforming an image to simulate the visibility associated with a particular Contrast Sensitivity Function (CSF) using a digital normal photograph (LDR).

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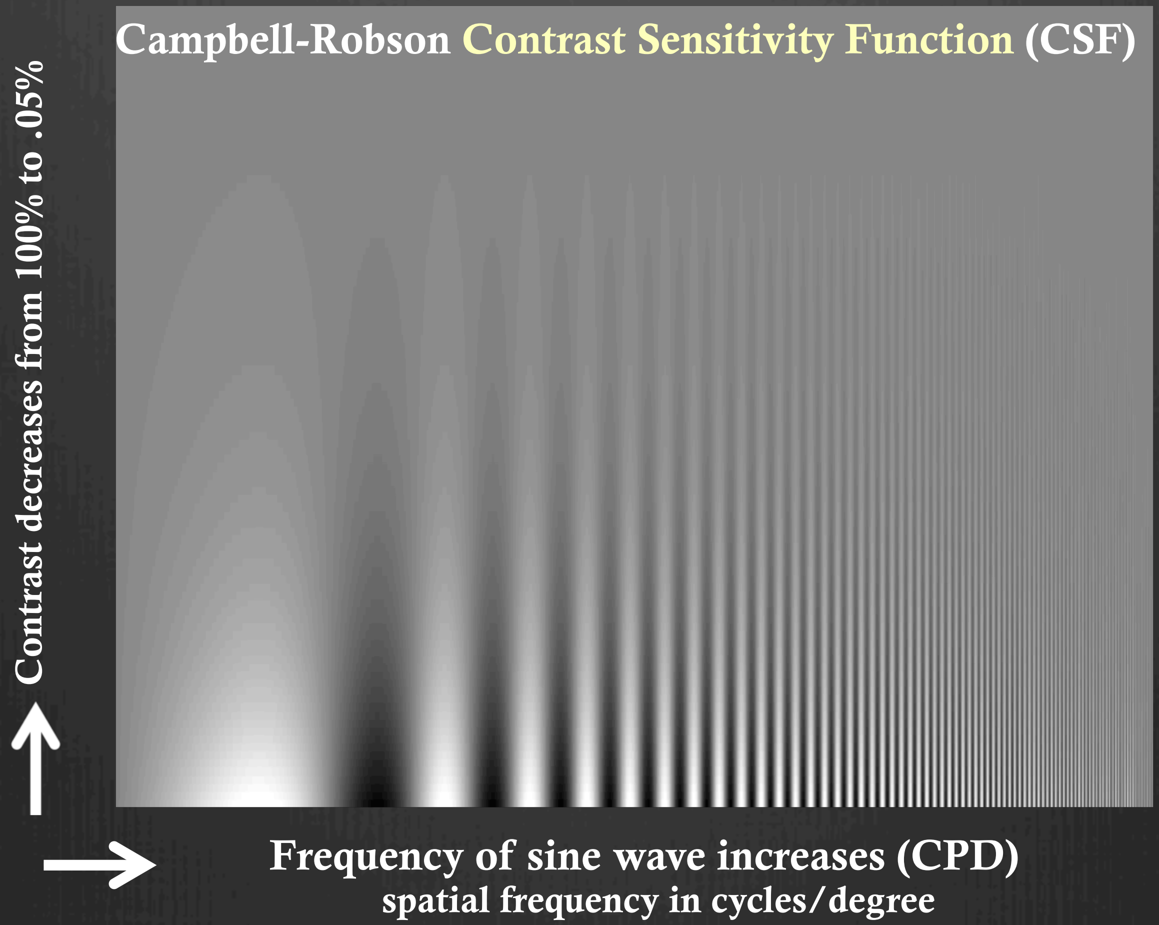

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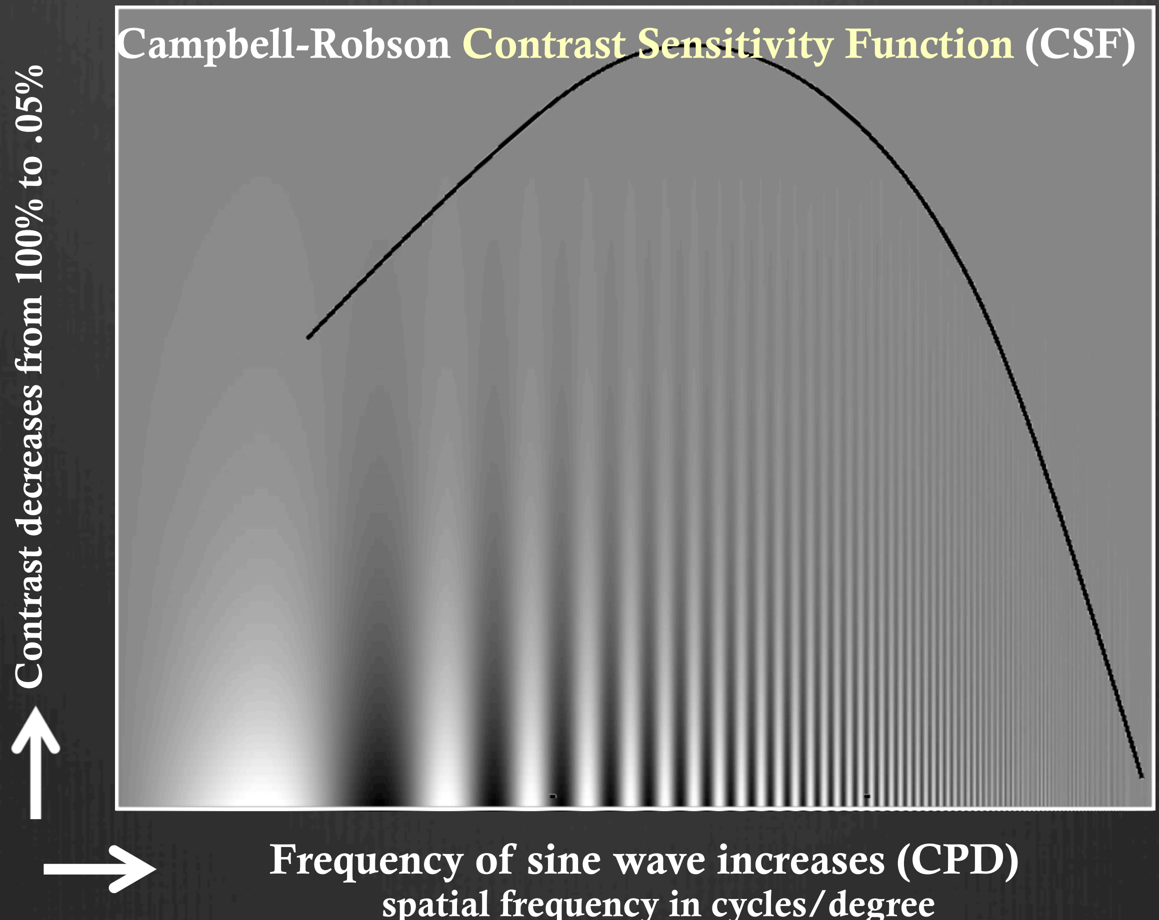

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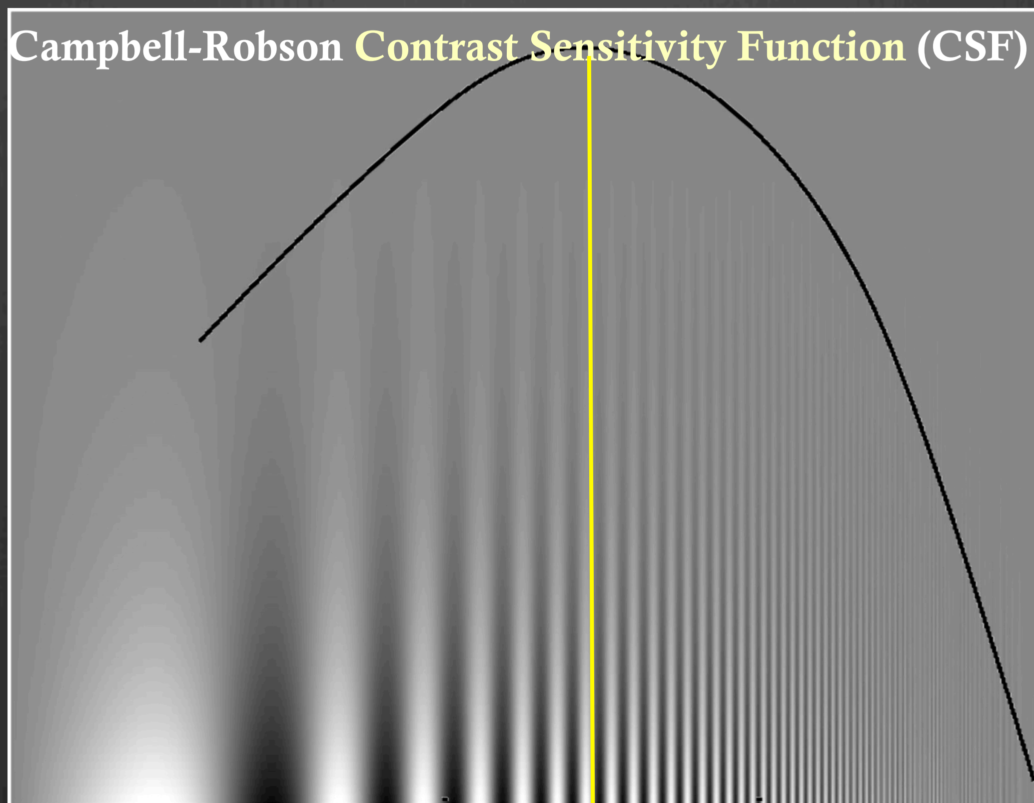

Contrast decreases from 100% to .05%

Frequency of sine wave increases (CPD)
spatial frequency in cycles/degree

CS peaks at 2 CPD for normal 20/20

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- Several functional forms of the CSF in modeling human vision
- we chose the only one that has been shown to fit empirical data from a group of low-vision subjects. (Chung and Legge: 2016)

Slide left for reduced Acuity – Slide down for reduced Contrast Sensitivity

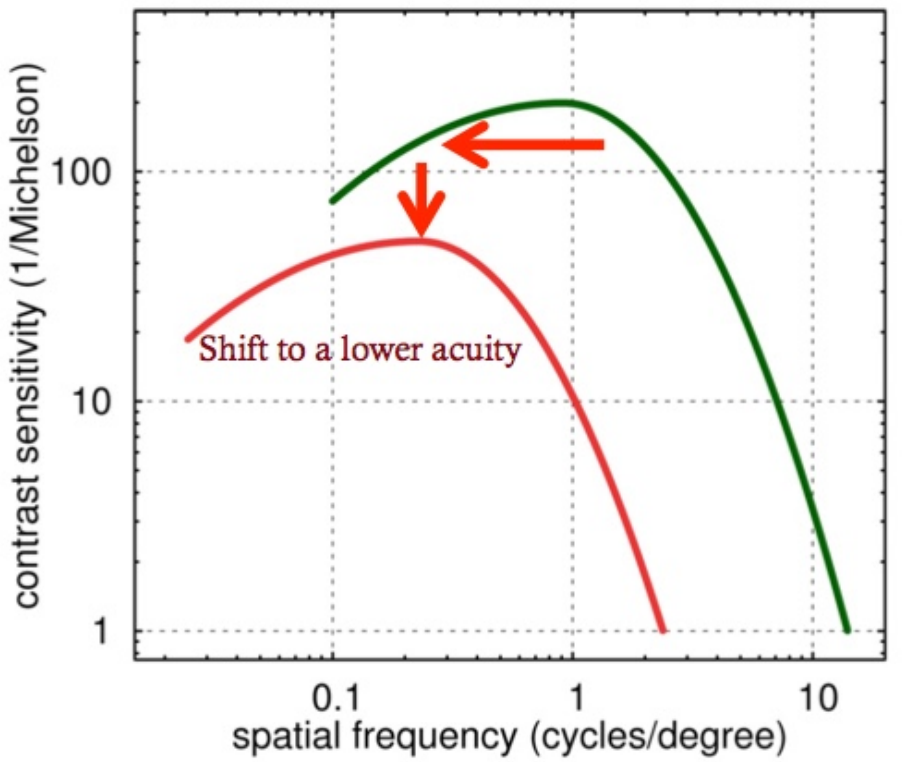

Fig. 1.
The Chung & Legge [15] CSF is an asymmetric parabola when plotted in $f_l - S_l$ space. The plotted values show two instances of the CSF, one shifted left (lower acuity) and down (lower contrast sensitivity) compared to the other.

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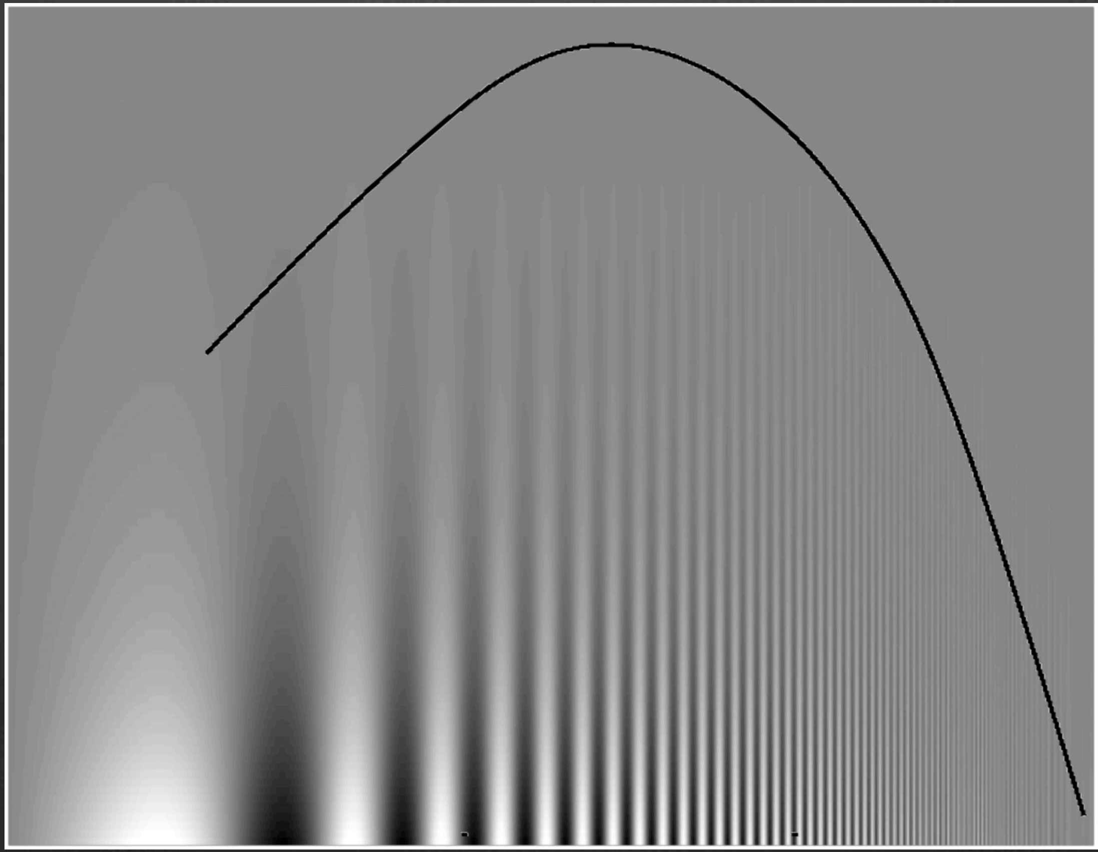

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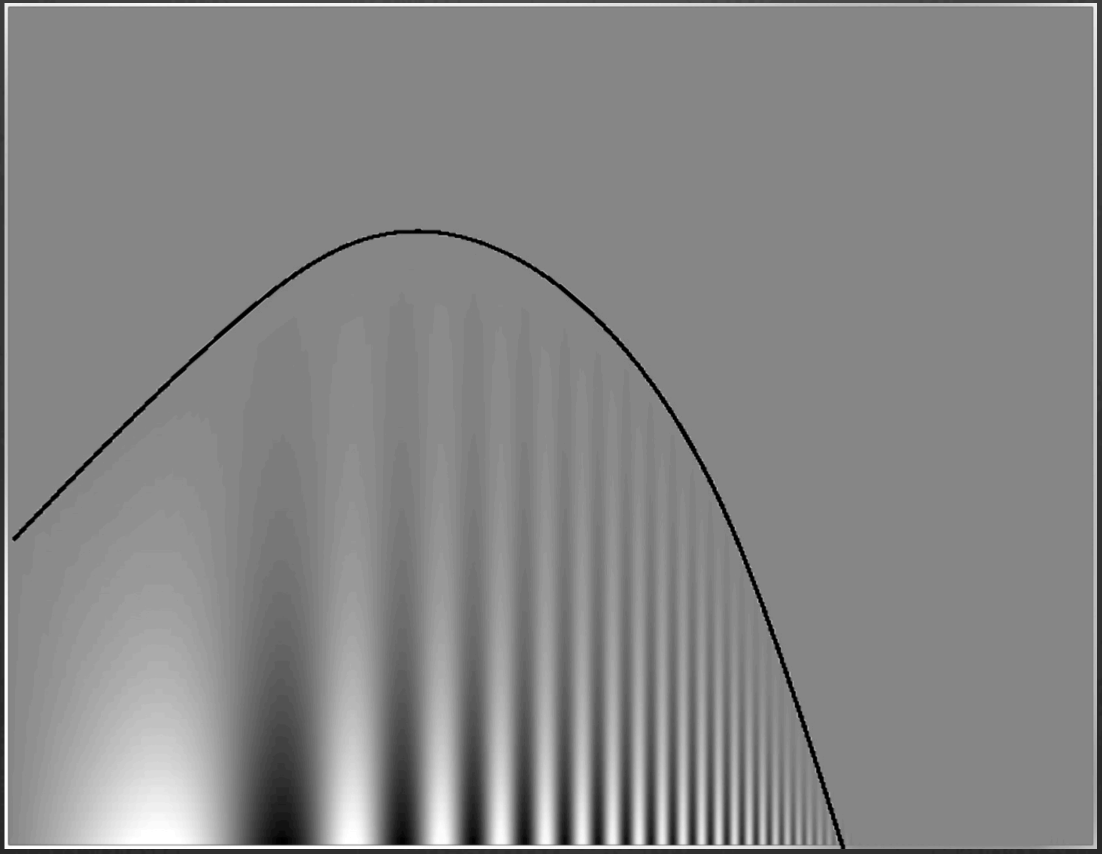
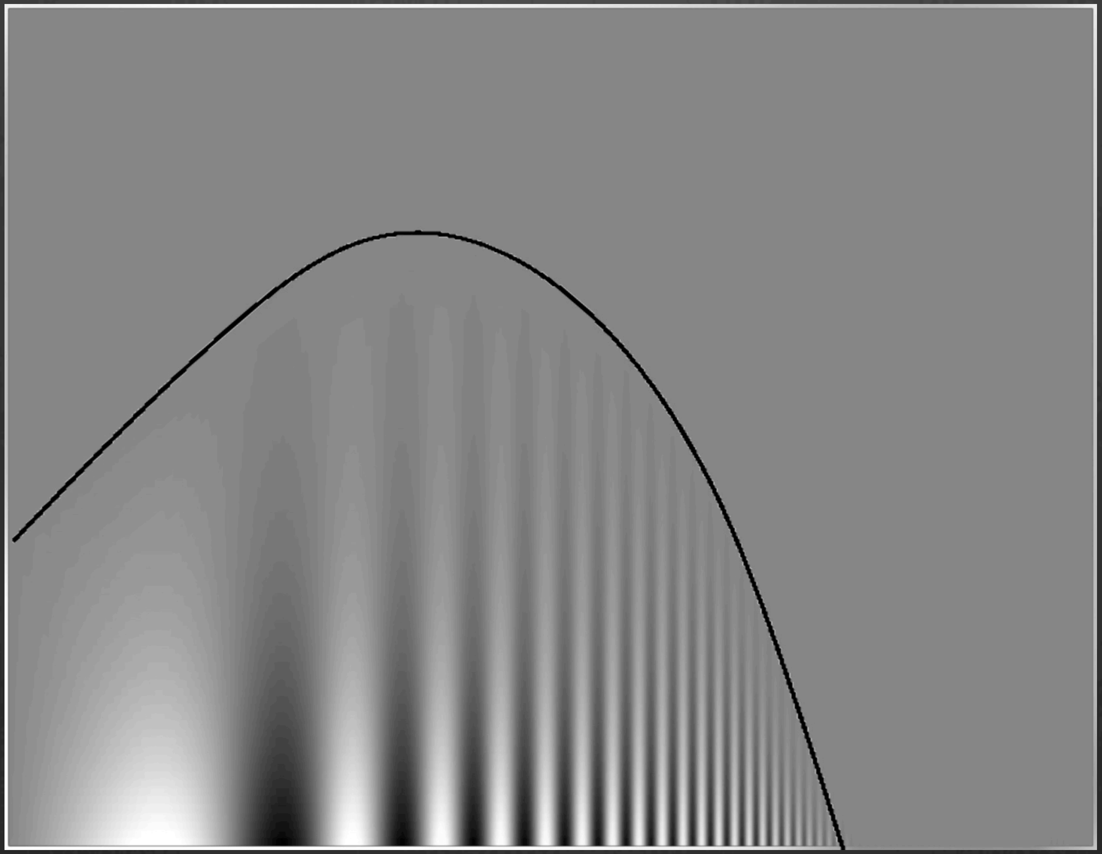


-An image is first transformed into a set of bandpass images, each representing an unnormalized contrast measure over a narrow range of spatial scales.



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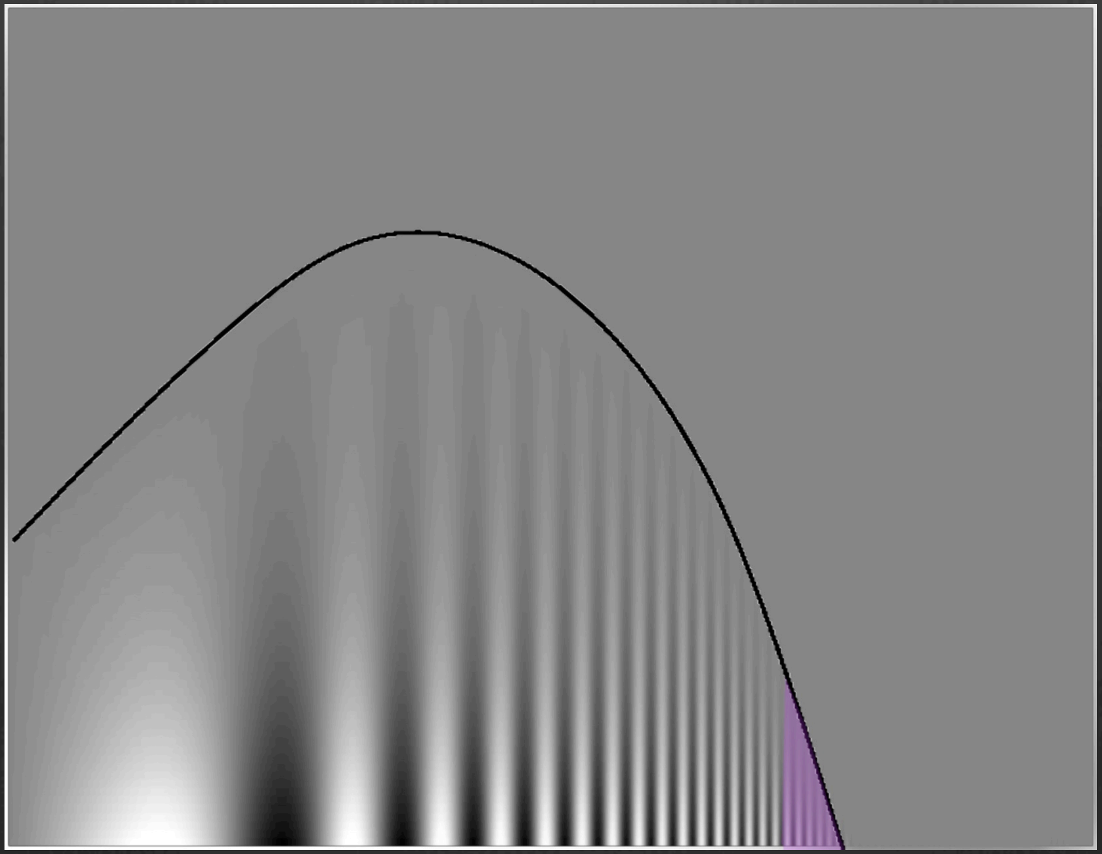

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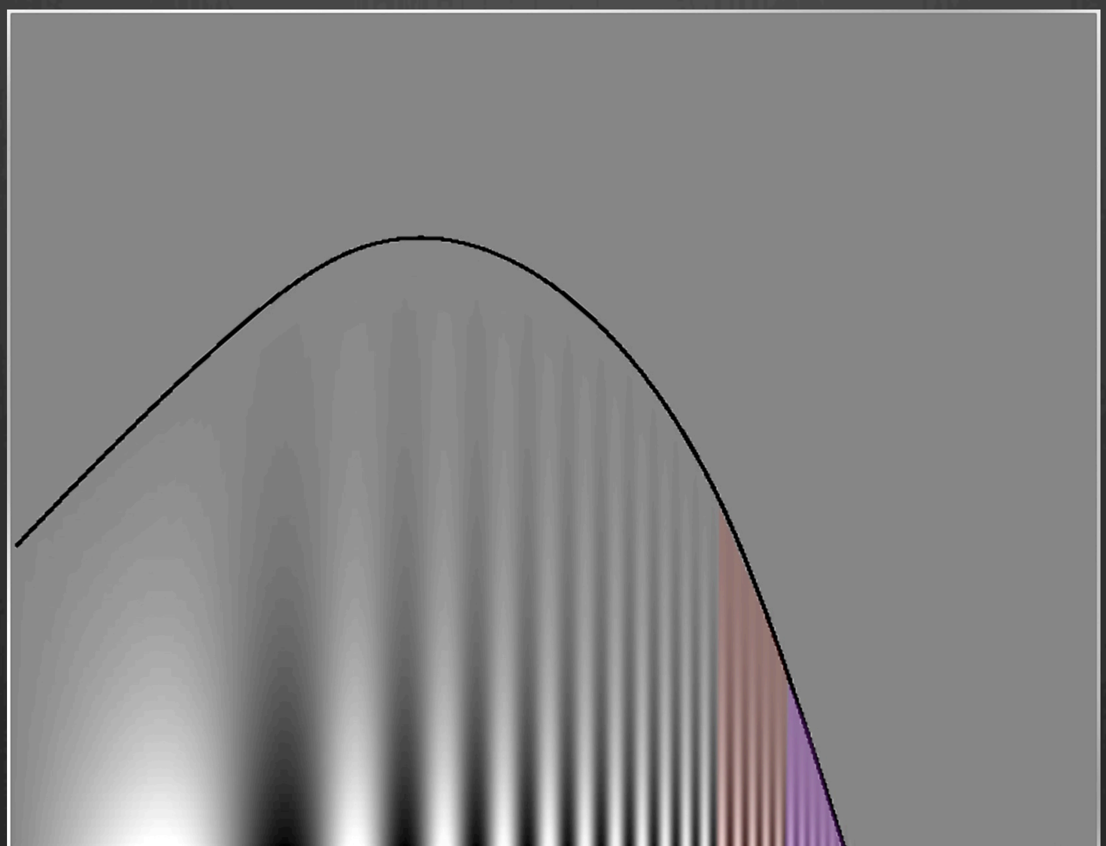

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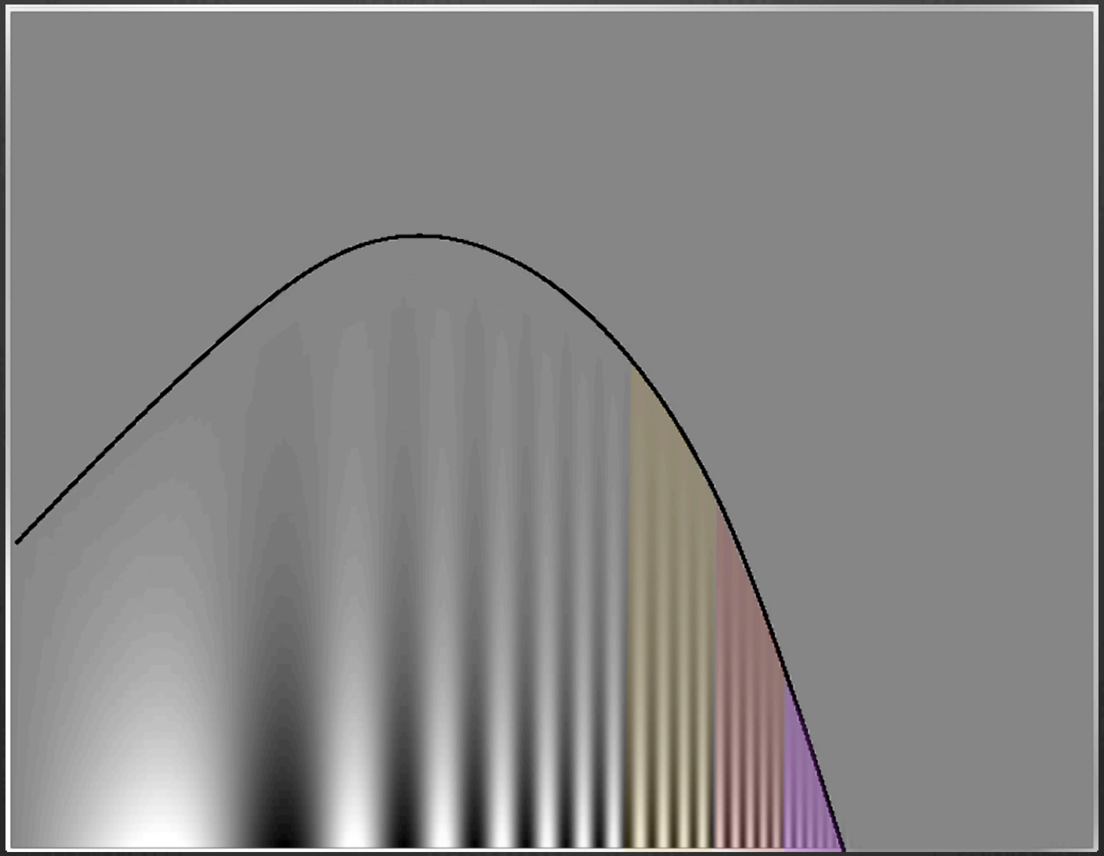

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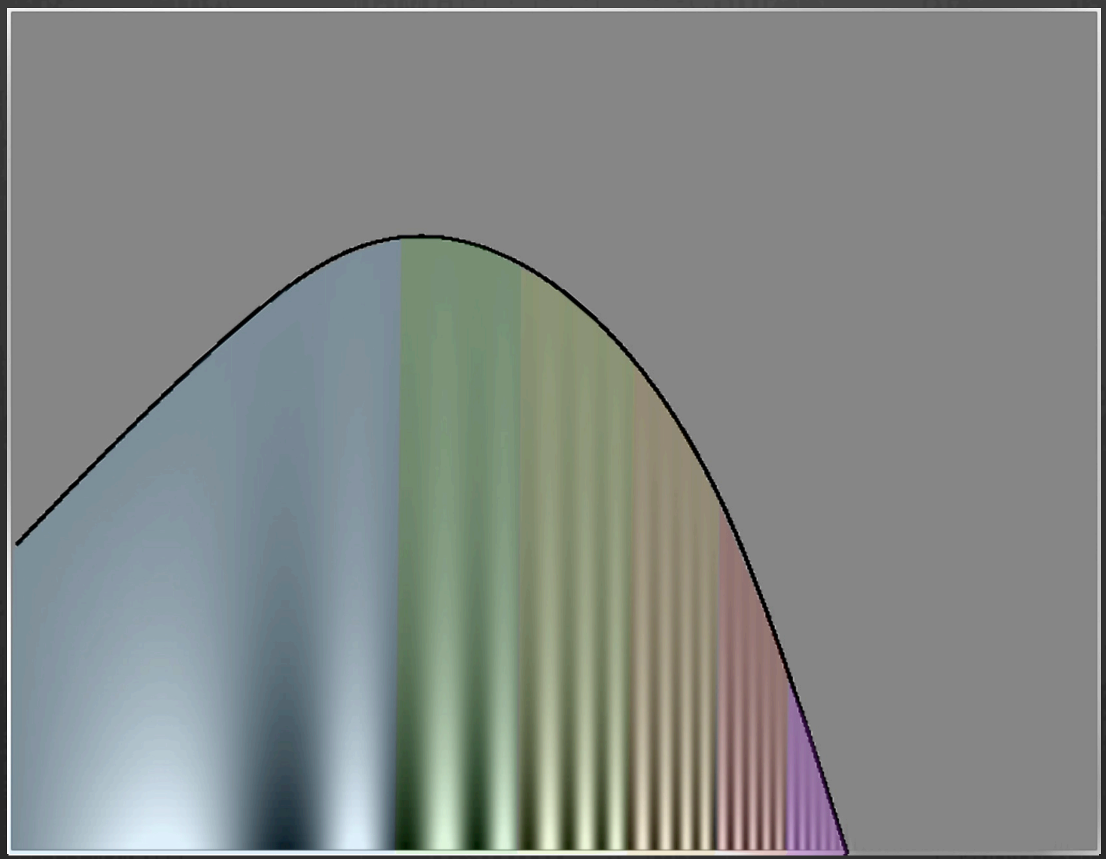
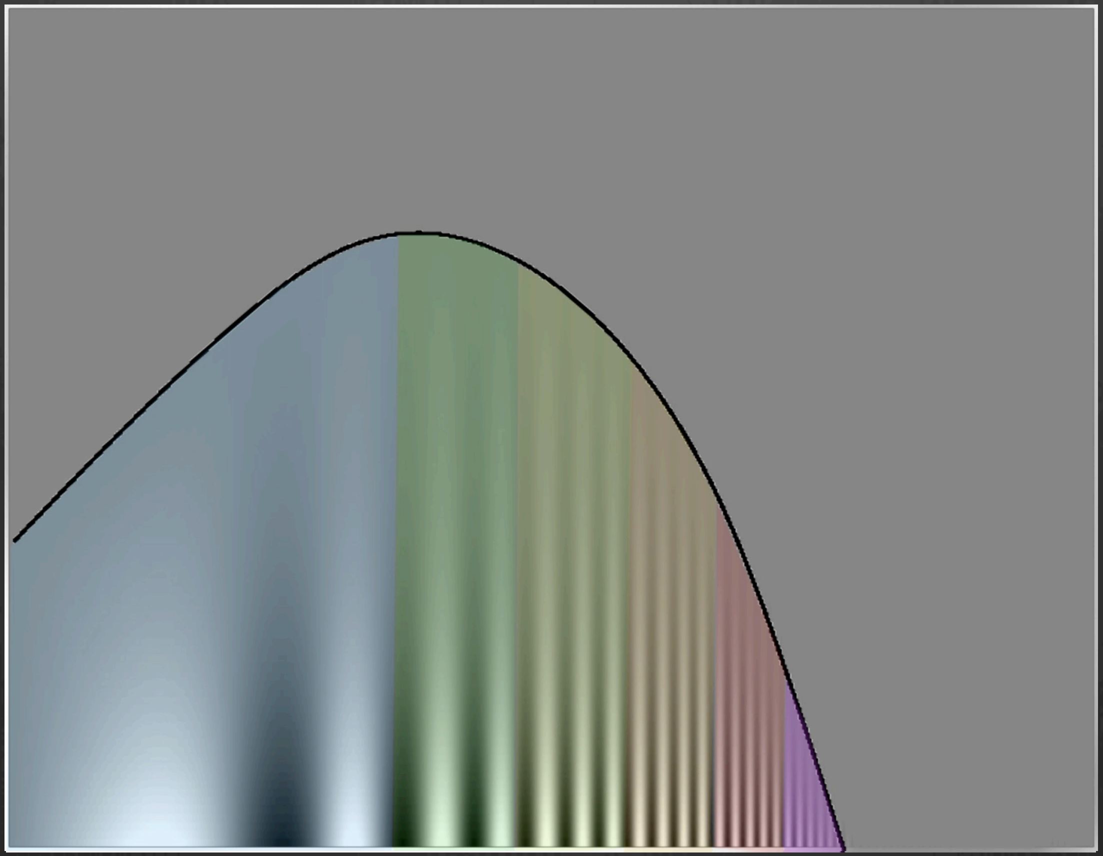


-Each pixel in each band is processed to provide a measure of local contrast.

-Then thresholded on a criterion that compares local contrast values to the peak sensitivity frequency of the band filter.

-The thresholded contrast bands are reassembled to produce an output image.



Advantages over a linear filtering including:

1. Contrast that is below the specified CSF is removed, rather than being attenuated. This reduces variability related to designer viewing conditions.
2. Contrast above the CSF threshold is left intact.
3. This spatially localized approach takes into account local luminance, which has a strong effect on contrast perception.

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Together, these properties:

remove image details predicted to be not visible,
while leaving intact, details predicted to BE visible.

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Our most significant contribution is that we calibrated the parameterized simulation using human subject studies as little is known about the relationship between contrast sensitivity and letter charts, as used in specifying the degree of visual degradation.

Subjects judged the readability of letters presented in various simulated acuities and contrast values.

(a) (b)

The resulting data was integrated into the filter

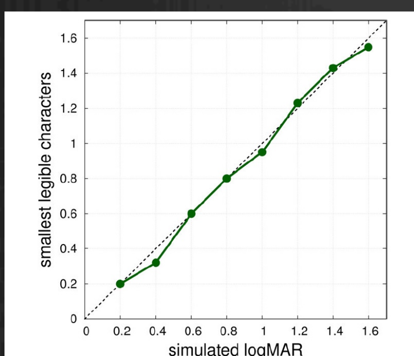


Fig. 5.
Empirically determined acuity for simulated low vision with *FPN* = 0.915 cycles/degree

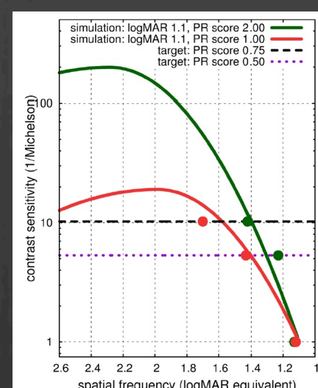


Fig. 6.
Empirically determined smallest legible characters for reduced acuity and contrast sensitivity.

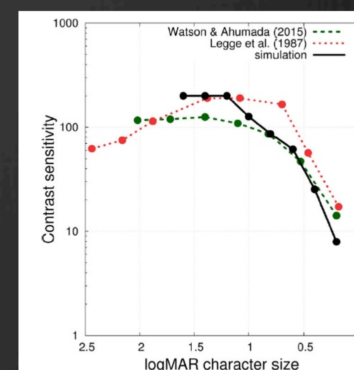
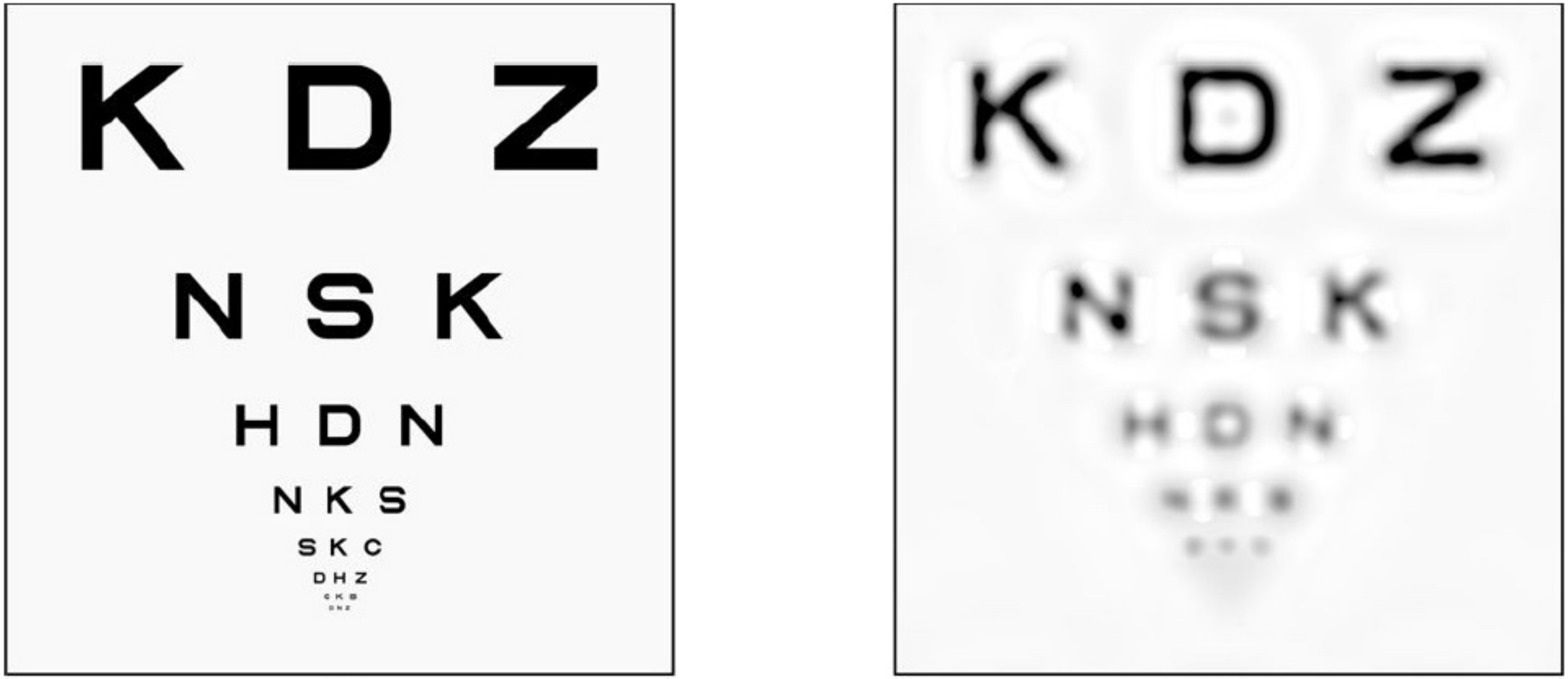


Fig. 7.
Empirically determined contrast sensitivity for simulated normal vision.



(a) (b)

Fig. 8.

(a) Original logMAR chart, with third line from top corresponding to logMAR 1.1 and the fourth line from the top corresponding to logMAR 0.9. For correct character size, view the chart from a distance equivalent to 3.33 times the width of the chart image. (b) Original logMAR chart, filtered to simulate an acuity of logMAR 1.0. The third line is readable, the fourth line is not.

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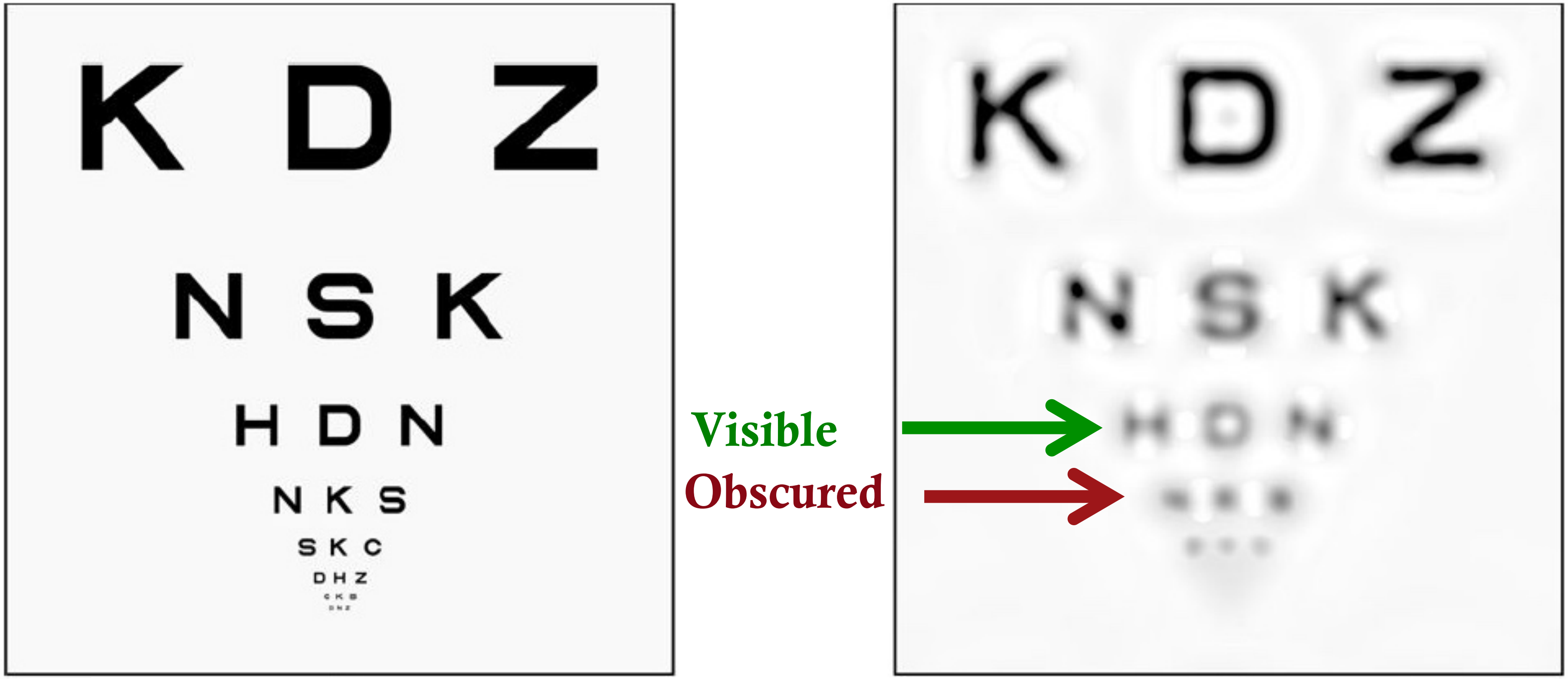

(Legal Blindness: 20/200 or less with best possible correction)

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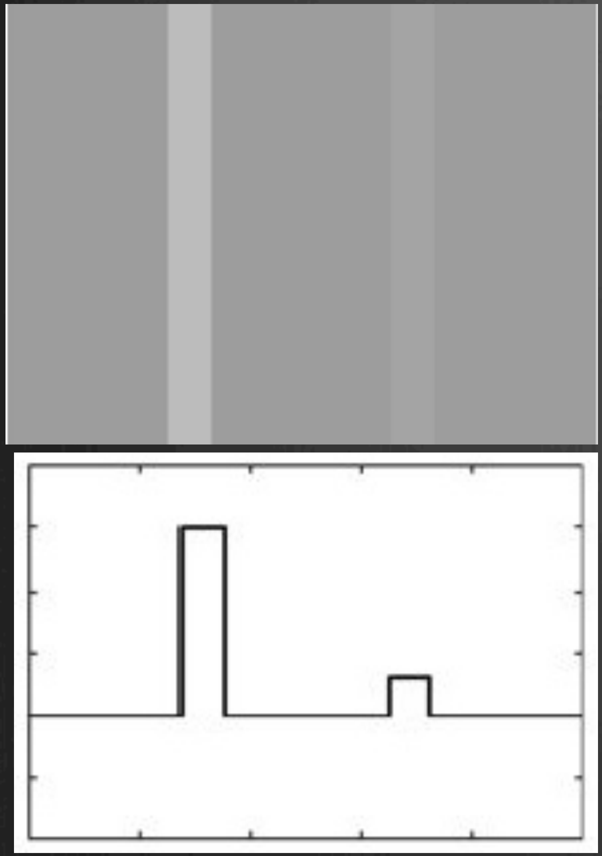
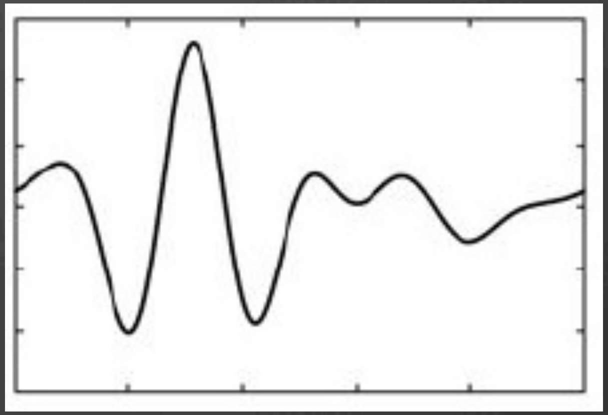
Reducing banding and artifacts in the simulations built on HDR images



Luminance profile



Bands produced by low vision simulation filter

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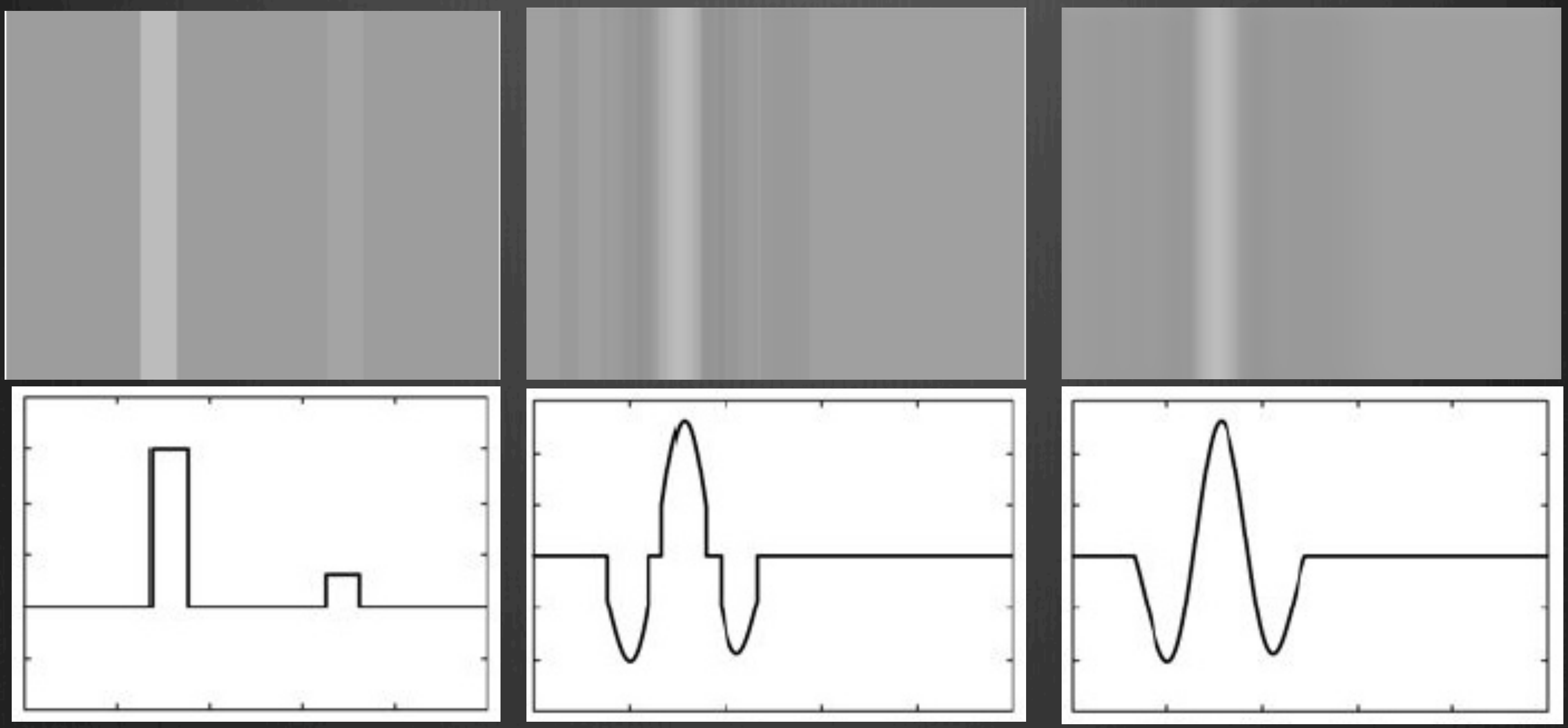

Luminance profile **thresholding of band** **improved thresholding**

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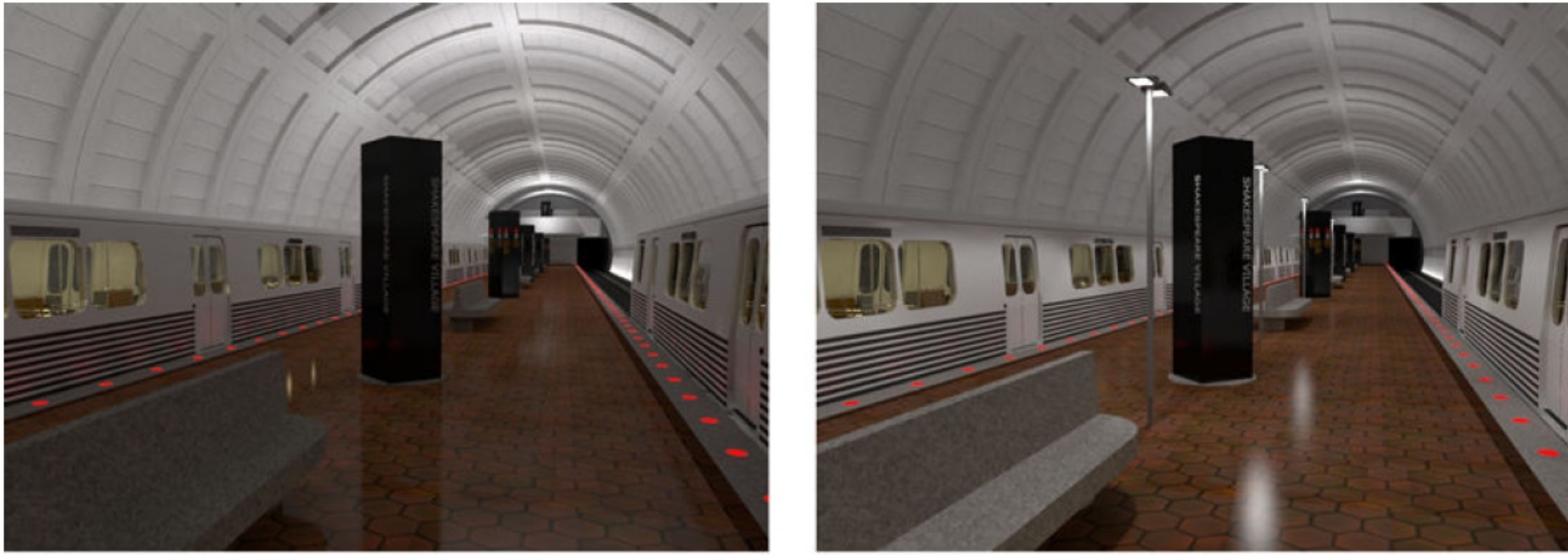

Original RADIANCE renderings.

Original filtered to simulate moderate low vision.

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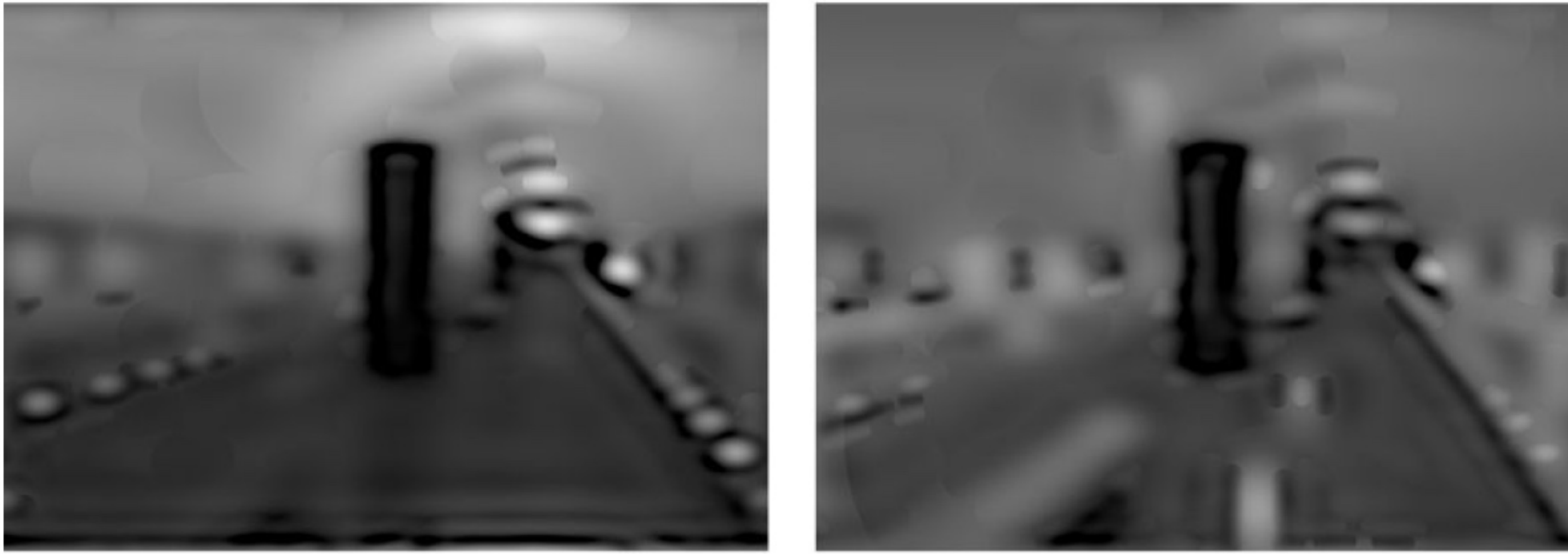

Original filtered to simulate severe low vision.

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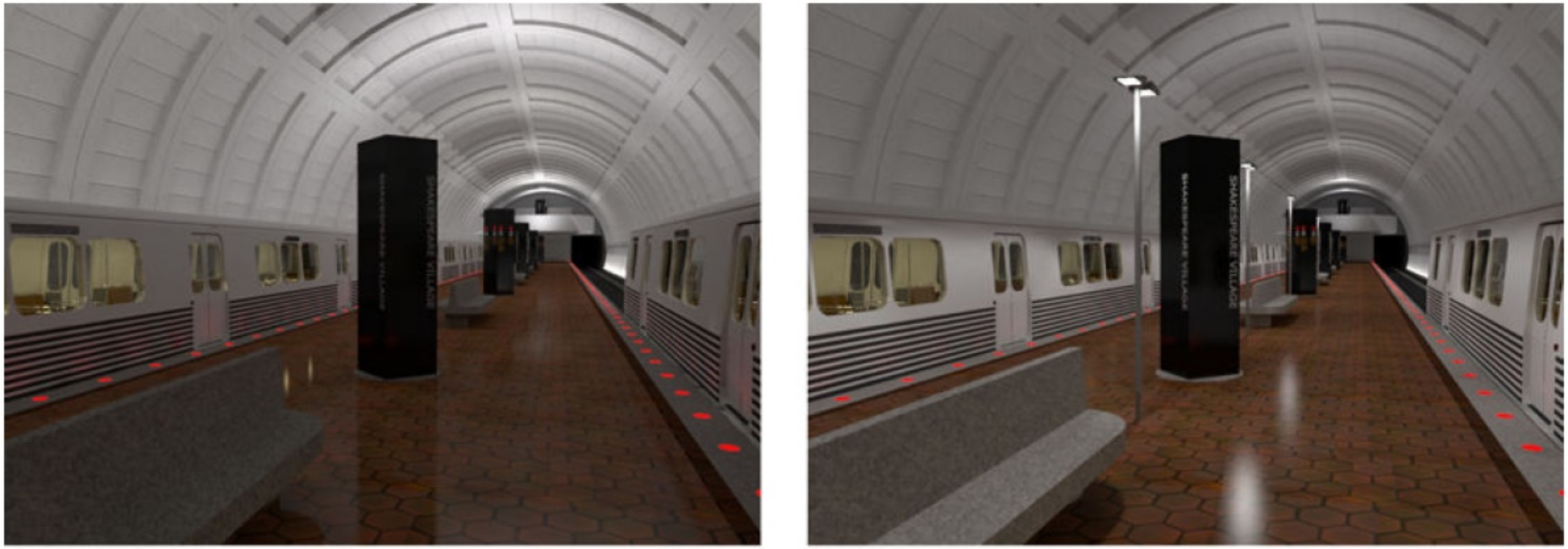

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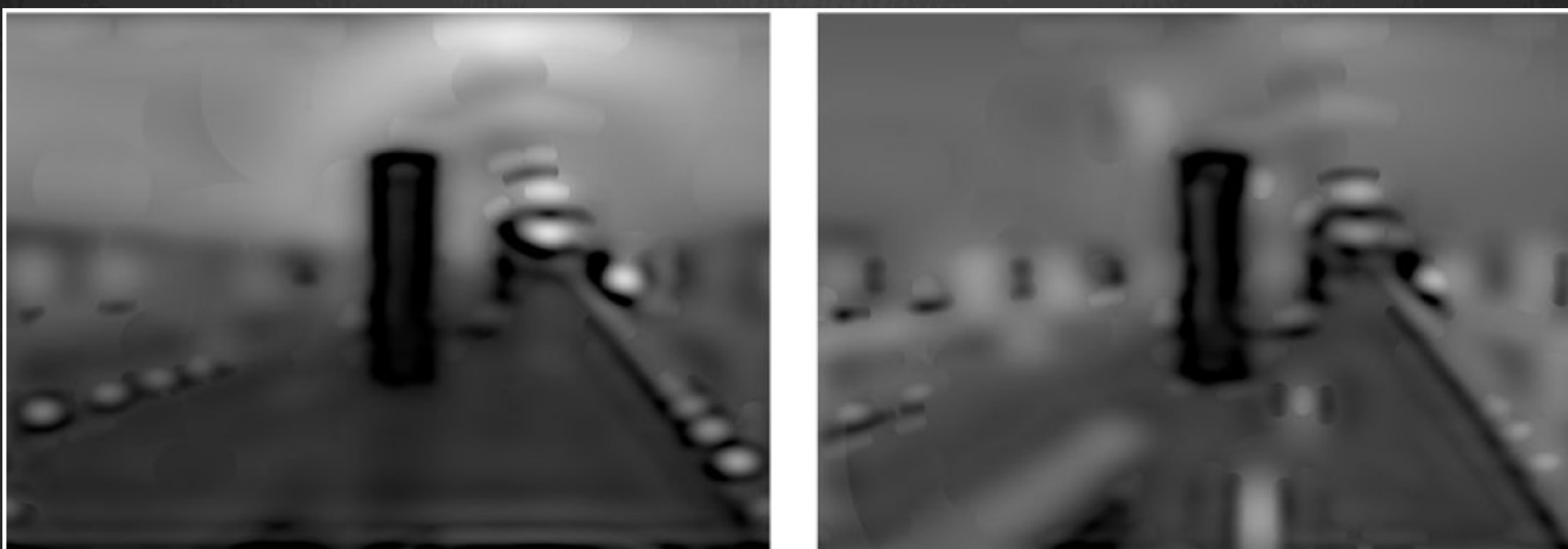


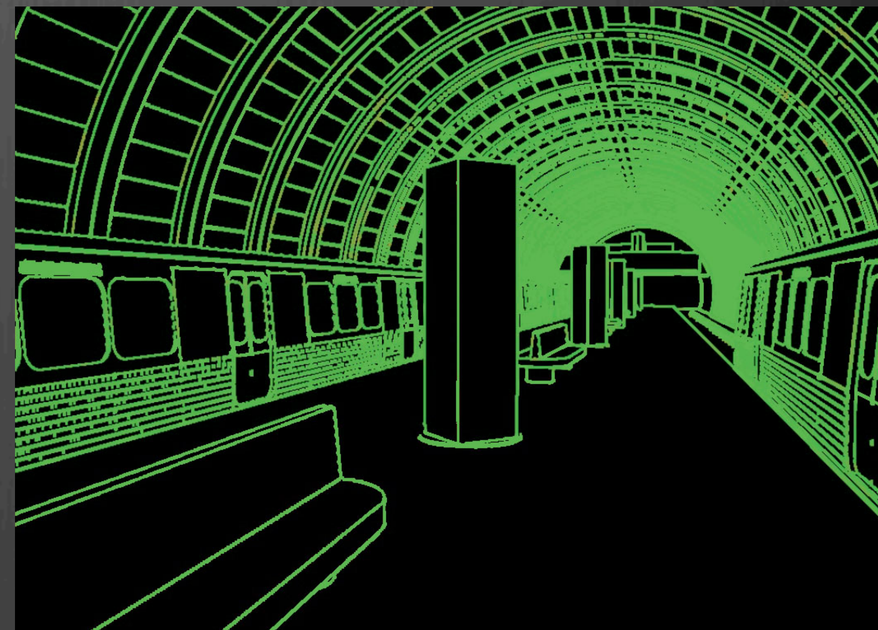
Original filtered to simulate severe low vision.

Current work

With the validation of the visibility prediction filter for HDR images behind us,

work continues on the automatic mobility hazard detector, and its validation.

Current work



Radiance Data Set → Ground Truth Edges

```
## create normal at surface text file
        set  norflnm = $bfnm"nor"$t
        vwrays -fd $dirhdrfnm | rtrace -fda `vwrays -d $dirhdrfnm` -on $octree >  $subd/$norflnm &
## create distance to surface text file
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.
.
.
```
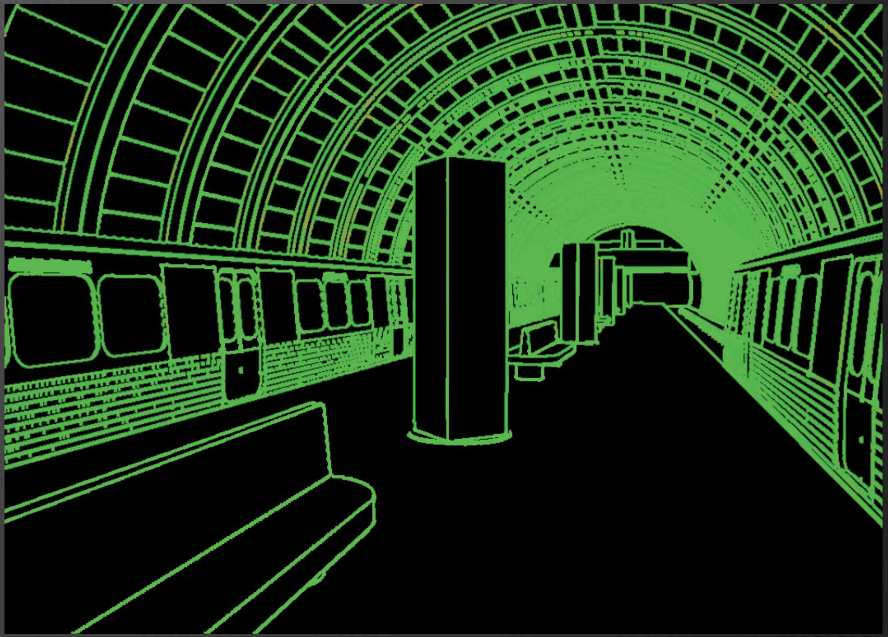

Current work

Occlusions: determine the average distance between a surface point in the patch and a plane passing through the center point of the patch and with an orientation matching the orientation of the modeled surface as the center of the patch.

Creases: compute the average over the patch of the difference of surface orientations at equal but opposite distances from the patch center.



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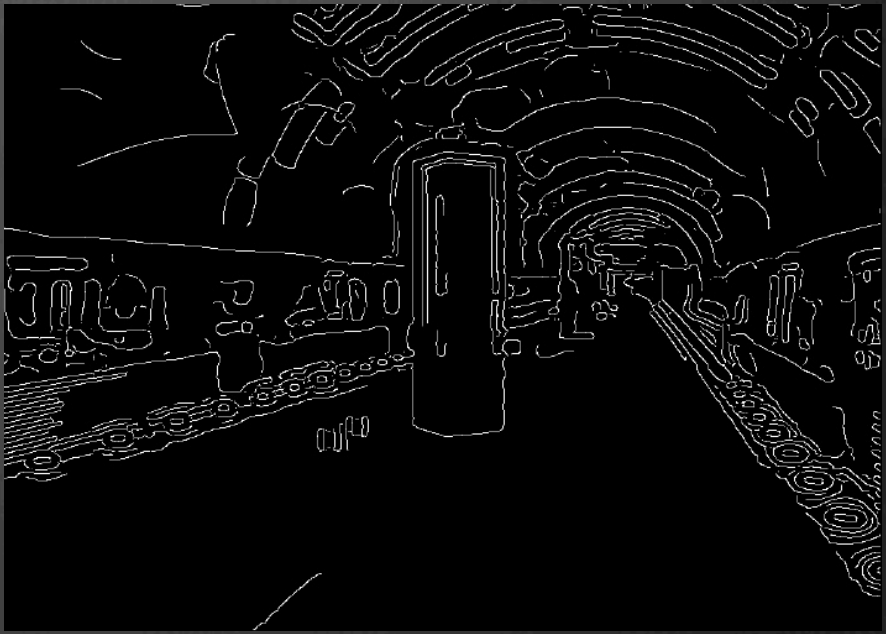
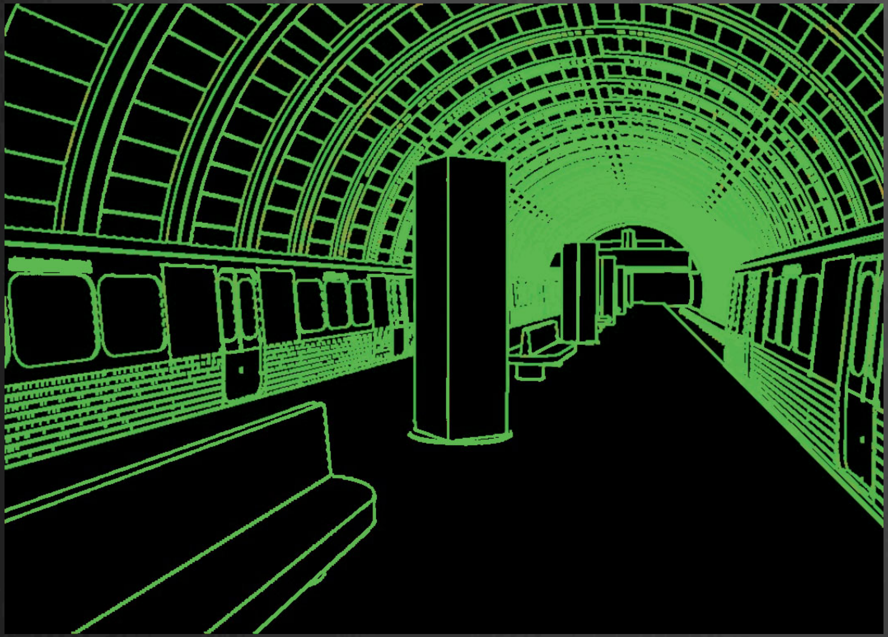
Current work

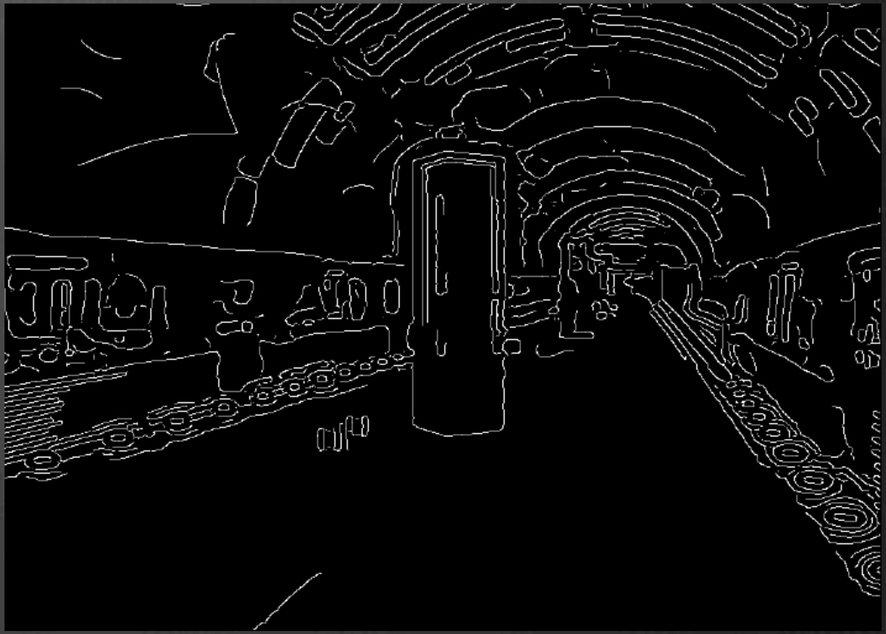


Severe Low Vision → Edge Detection of HDR Image
(luminance boundaries)

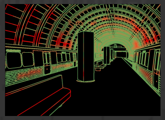
Current work



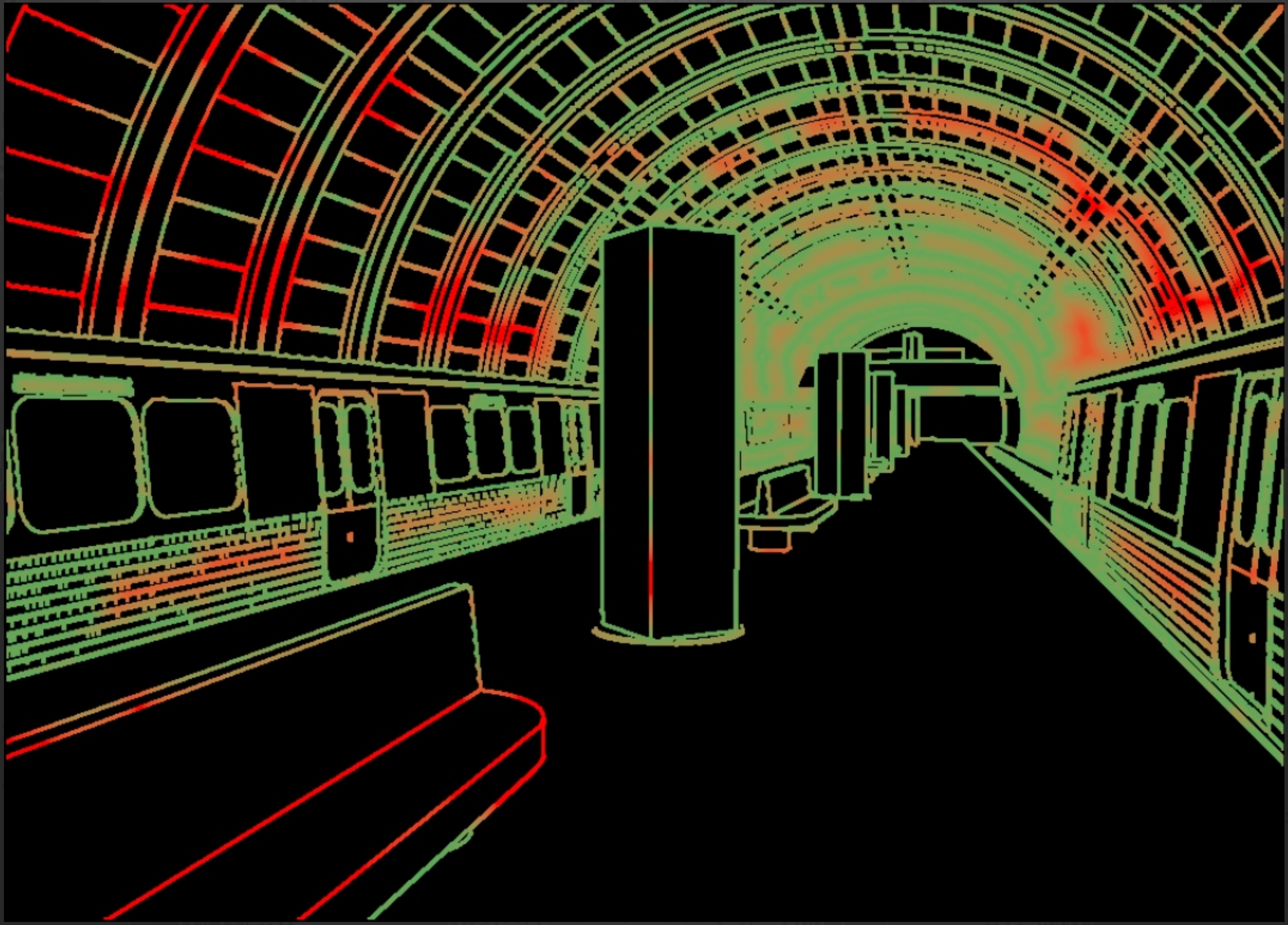
Ground Truth Edges



Edge Detection of HDR Image

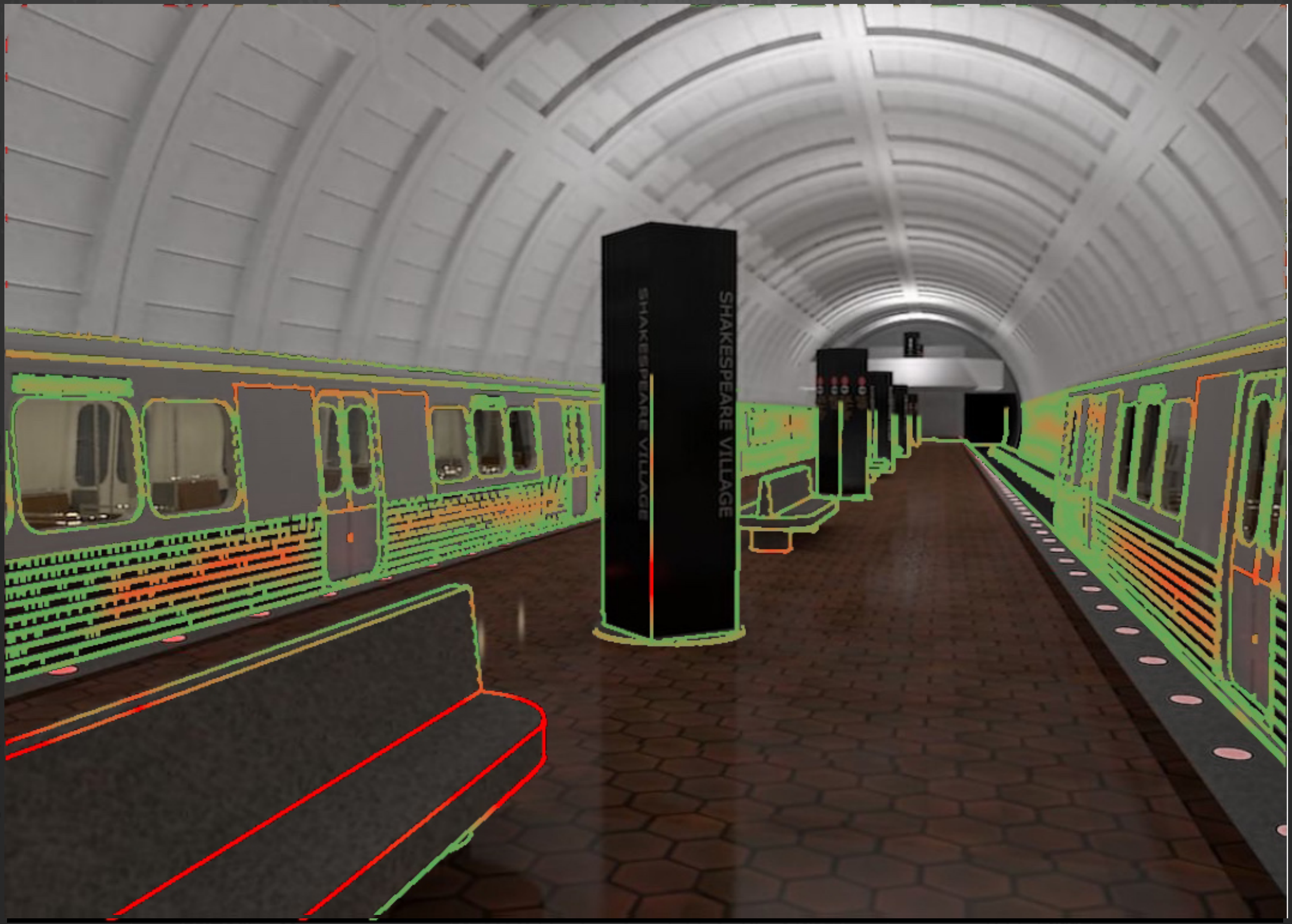


Current work



RED edges predicted NOT to be visible

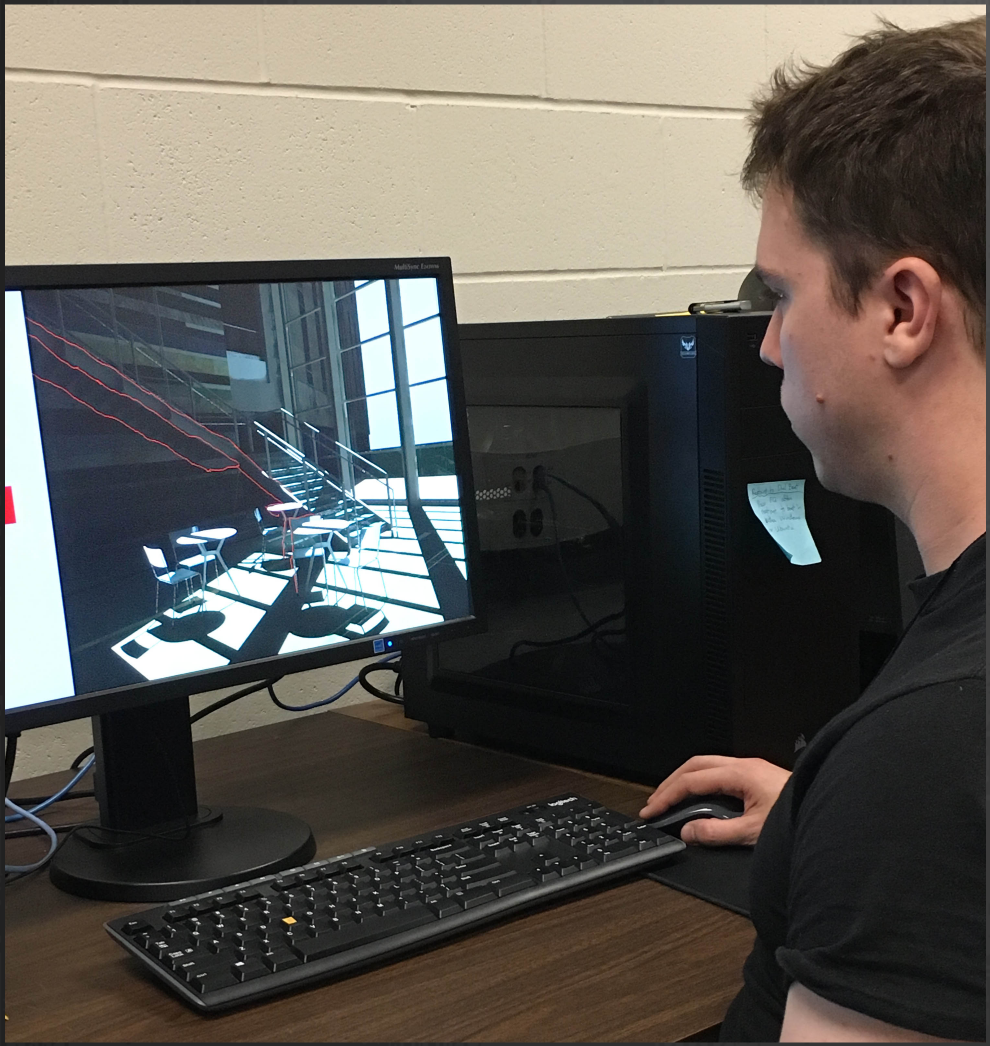
Current work



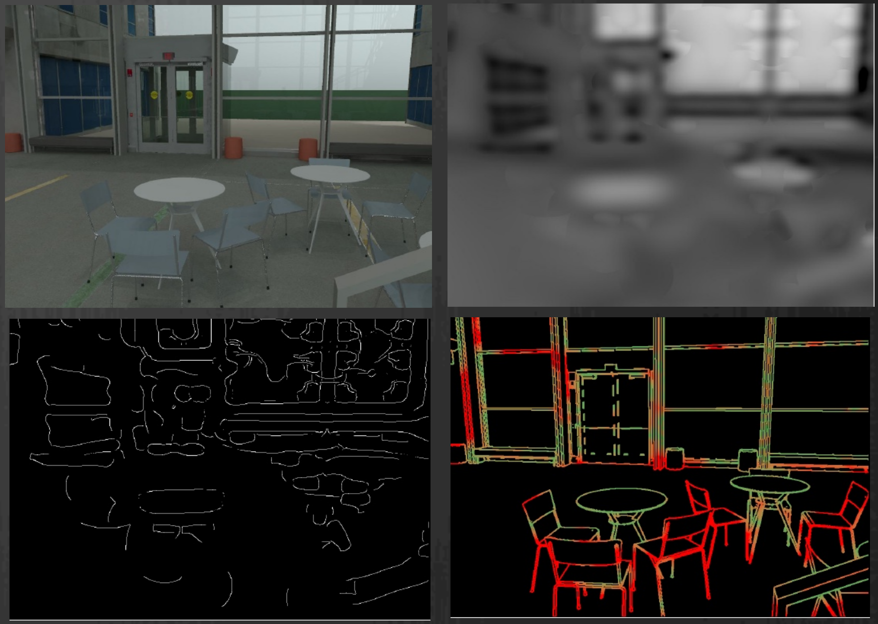
RED edges predicted NOT to be visible

Current work

Current work



Validation studies include "edge labeling" on images: normal and processed with the Low Vision Filter.



Visibility Prediction Studies

Visibility Prediction Studies

Visibility Prediction studies

20/45	20/115	20/285	20/710
LogMAR 0.35	LogMAR 0.75	LogMAR 1.15	LogMAR 1.55
color 75%	color 40%	color 25%	color 0%

Simulation of *mild* visual impairment.

Simulation of *moderate* low vision.

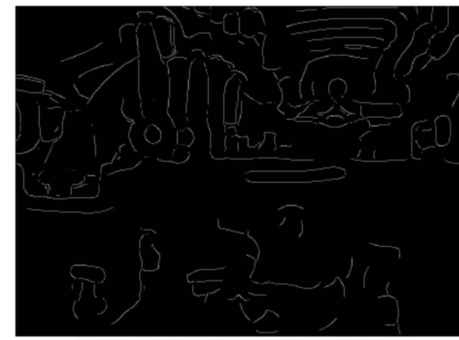
Simulation of *severe* low vision.

Simulation of *profound* low vision.

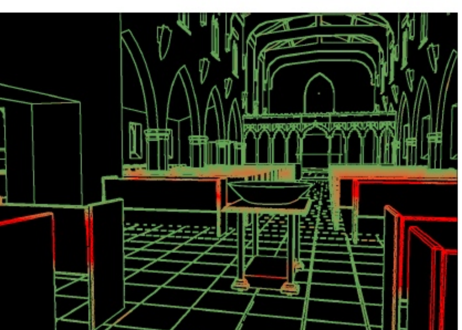
Canny edges for *mild* visual impairment.

Canny edges for *moderate* low vision.

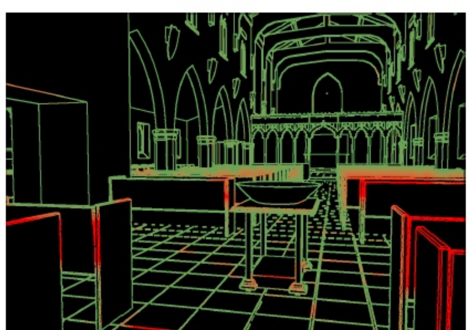
Canny edges for *severe* low vision.



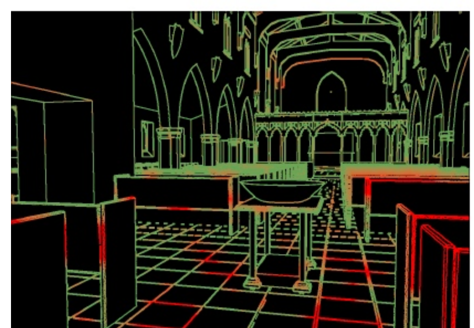
Canny edges for *profound* low vision.



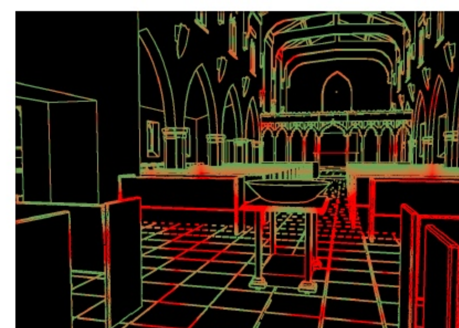
Predicted visibility of geometry under *mild* visual impairment.



Predicted visibility of geometry under *moderate* low vision.



Predicted visibility of geometry under *severe* low vision.



Predicted visibility of geometry under *profound* low vision.

Visibility Prediction studies

Visibility Prediction studies

Simulation of *mild* visual impairment.

Simulation of *moderate* low vision.

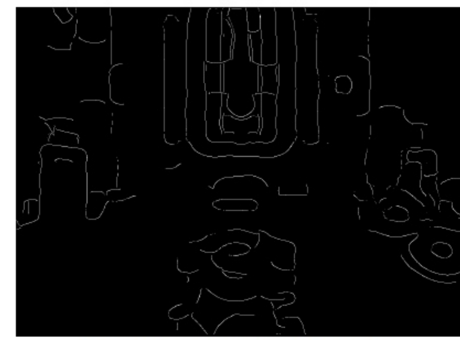
Simulation of *severe* low vision.

Simulation of *profound* low vision.

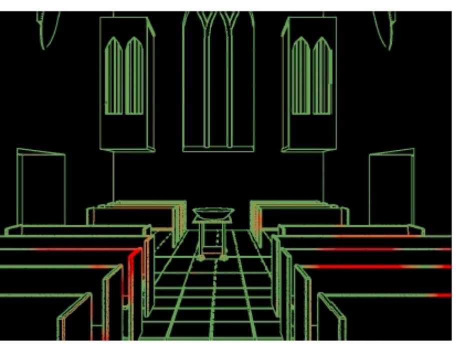
Canny edges for *mild* visual impairment.

Canny edges for *moderate* low vision.

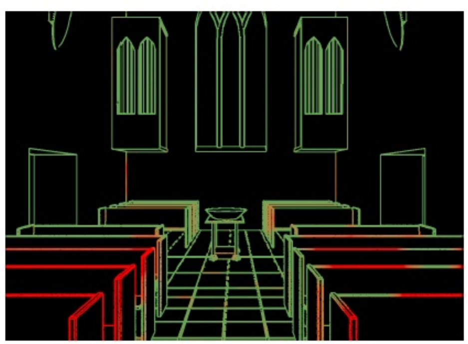
Canny edges for *severe* low vision.



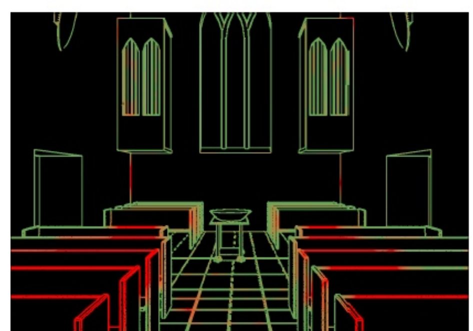
Canny edges for *profound* low vision.



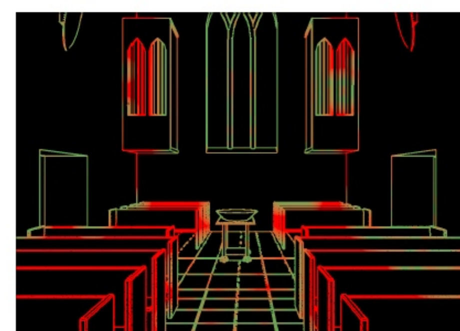
Predicted visibility of geometry under *mild* visual impairment.



Predicted visibility of geometry under *moderate* low vision.



Predicted visibility of geometry under *severe* low vision.

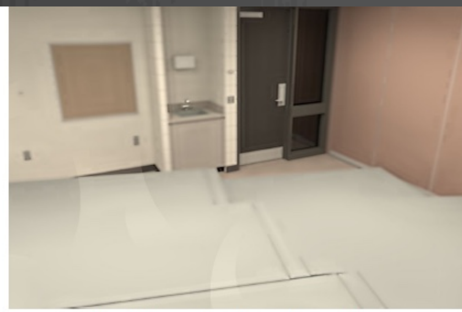


Predicted visibility of geometry under *profound* low vision.

Visibility Prediction studies

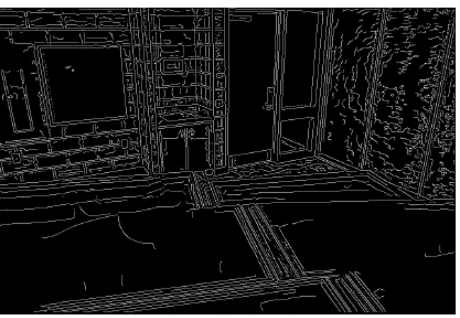
Visibility Prediction studies

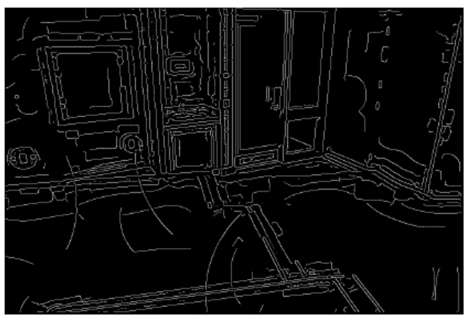

Simulation of *mild* visual impairment.

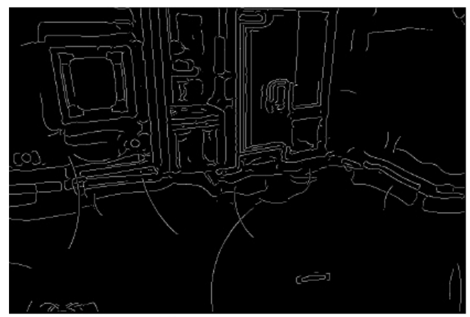

Simulation of *moderate* low vision.

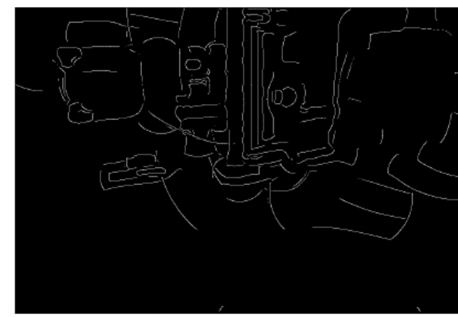

Simulation of *severe* low vision.

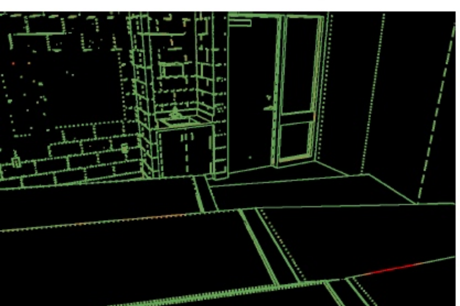

Simulation of *profound* low vision.

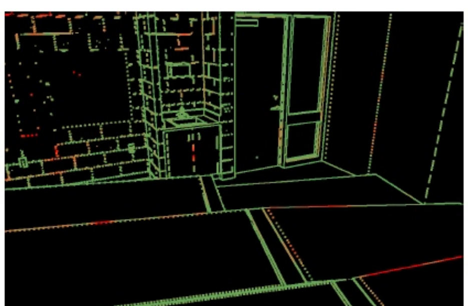

Canny edges for *mild* visual impairment.

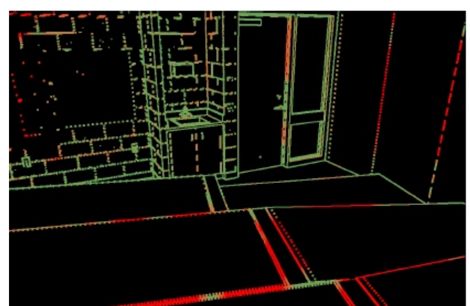

Canny edges for *moderate* low vision.

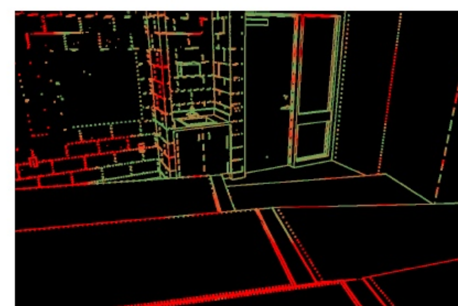

Canny edges for *severe* low vision.


Canny edges for *profound* low vision.

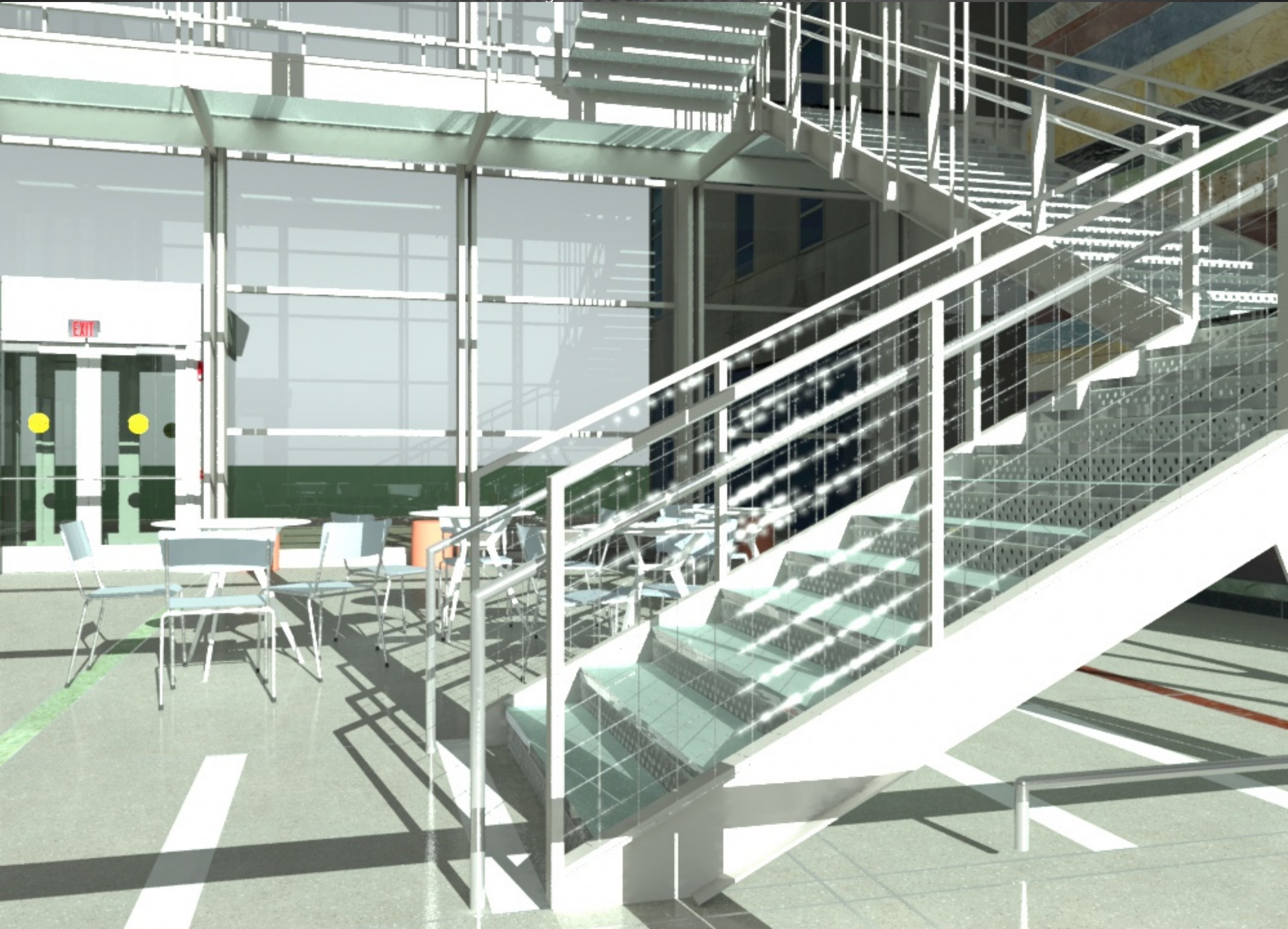

Predicted visibility of geometry under *mild* visual impairment.


Predicted visibility of geometry under *moderate* low vision.

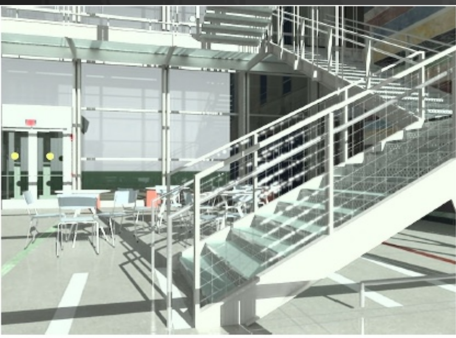

Predicted visibility of geometry under *severe* low vision.


Predicted visibility of geometry under *profound* low vision.

Visibility Prediction studies

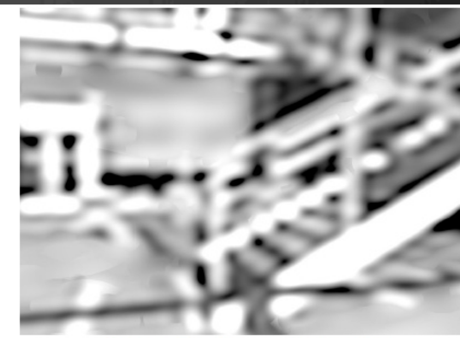


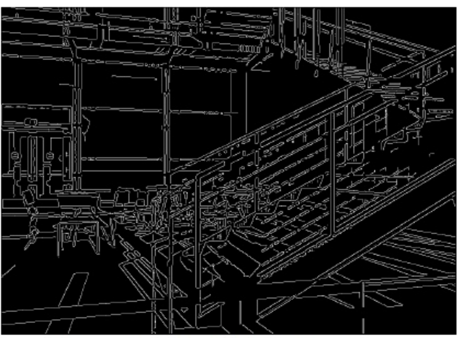
Visibility Prediction studies

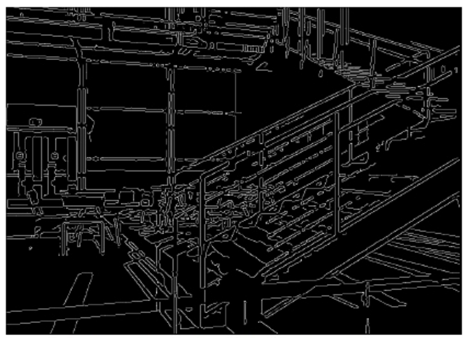

Simulation of *mild* visual impairment.

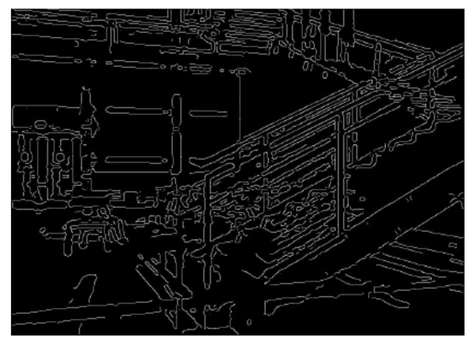

Simulation of *moderate* low vision.


Simulation of *severe* low vision.

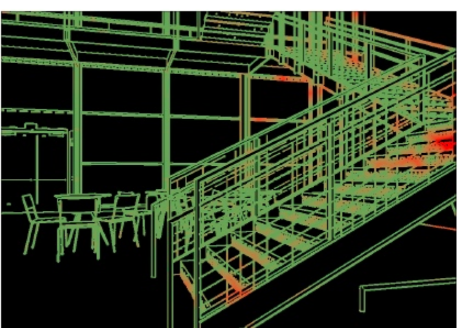

Simulation of *profound* low vision.

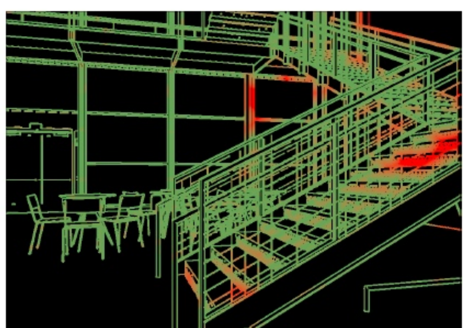

Canny edges for *mild* visual impairment.

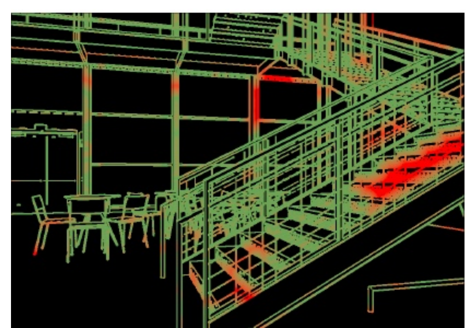

Canny edges for *moderate* low vision.

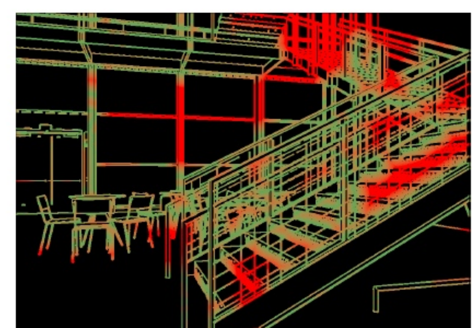

Canny edges for *severe* low vision.


Canny edges for *profound* low vision.


Predicted visibility of geometry under *mild* visual impairment.


Predicted visibility of geometry under *moderate* low vision.


Predicted visibility of geometry under *severe* low vision.

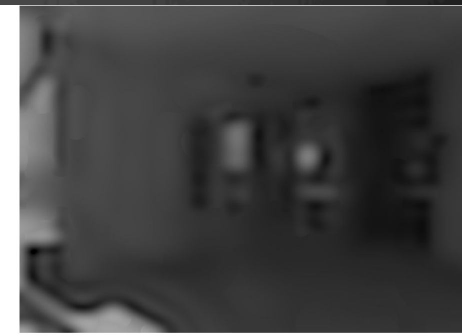

Predicted visibility of geometry under *profound* low vision.

Visibility Prediction studies

Simulation of *mild* visual impairment.

Simulation of *moderate* low vision.

Simulation of *severe* low vision.

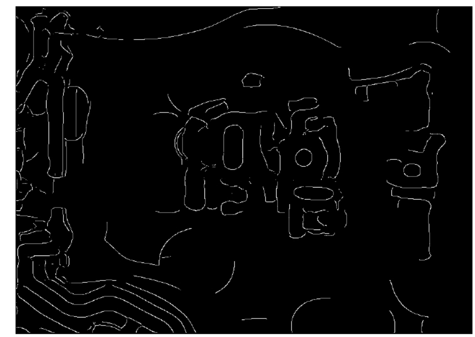


Simulation of *profound* low vision.

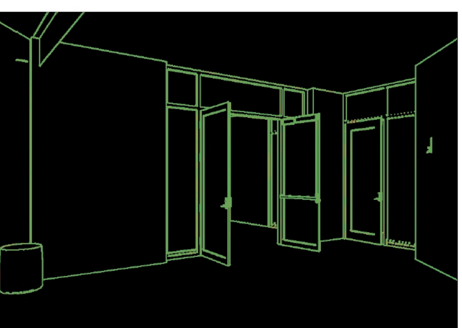
Canny edges for *mild* visual impairment.

Canny edges for *moderate* low vision.

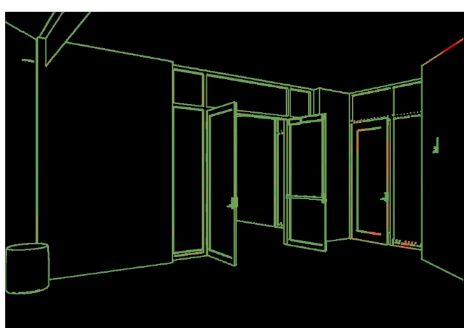
Canny edges for *severe* low vision.



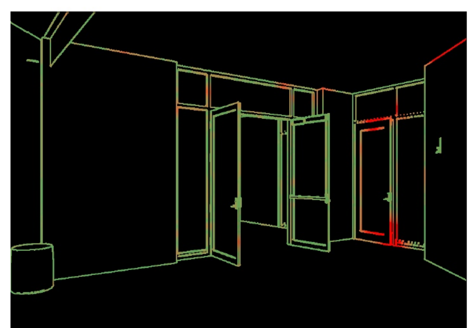
Canny edges for *profound* low vision.



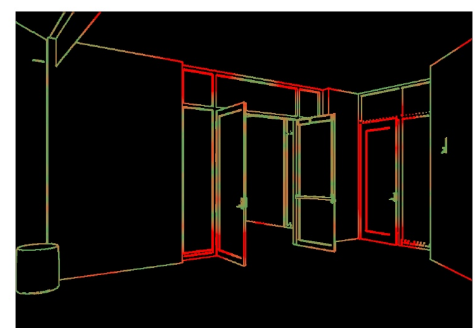
Predicted visibility of geometry under *mild* visual impairment.



Predicted visibility of geometry under *moderate* low vision.

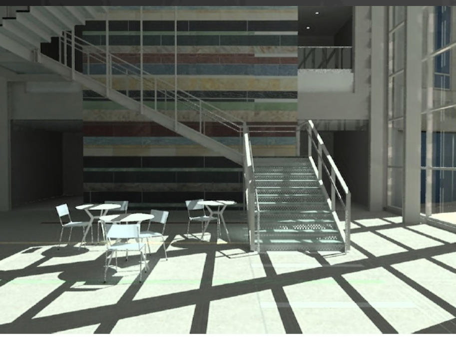


Predicted visibility of geometry under *severe* low vision.

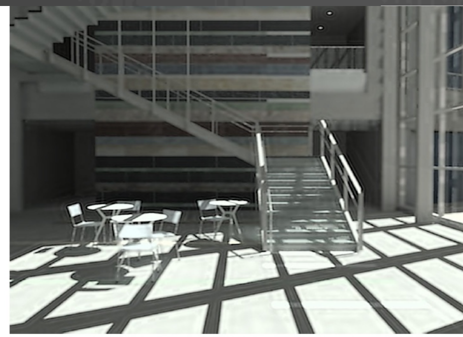


Predicted visibility of geometry under *profound* low vision.

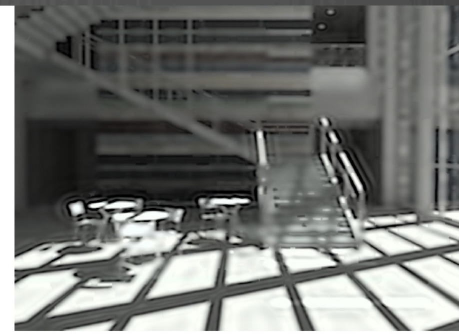
Visibility Prediction studies



Simulation of *mild* visual impairment.

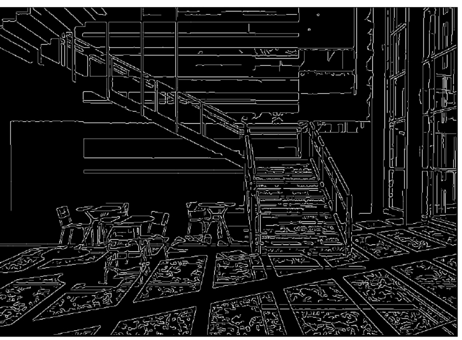


Simulation of *moderate* low vision.

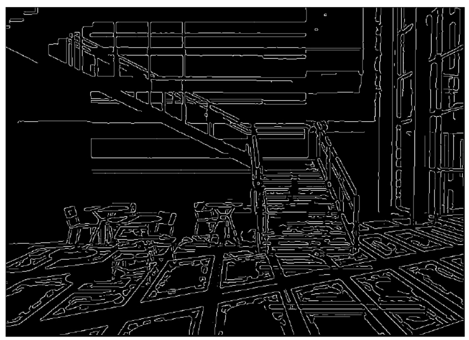


Simulation of *severe* low vision.

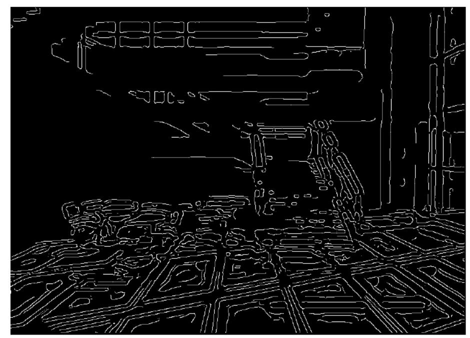
Simulation of *profound* low vision.



Canny edges for *mild* visual impairment.



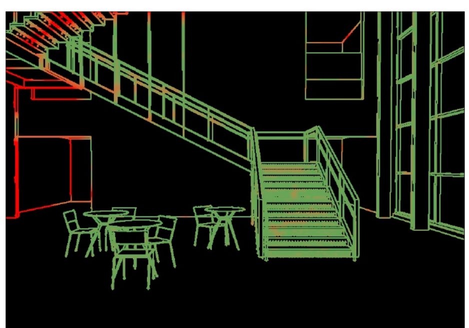
Canny edges for *moderate* low vision.



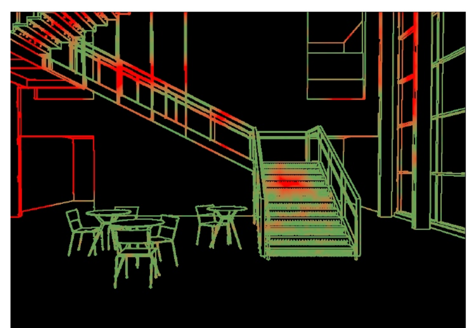
Canny edges for *severe* low vision.

Canny edges for *profound* low vision.

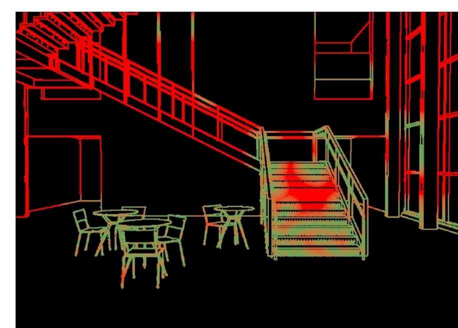
Predicted visibility of geometry under *mild* visual impairment.



Predicted visibility of geometry under *moderate* low vision.



Predicted visibility of geometry under *severe* low vision.

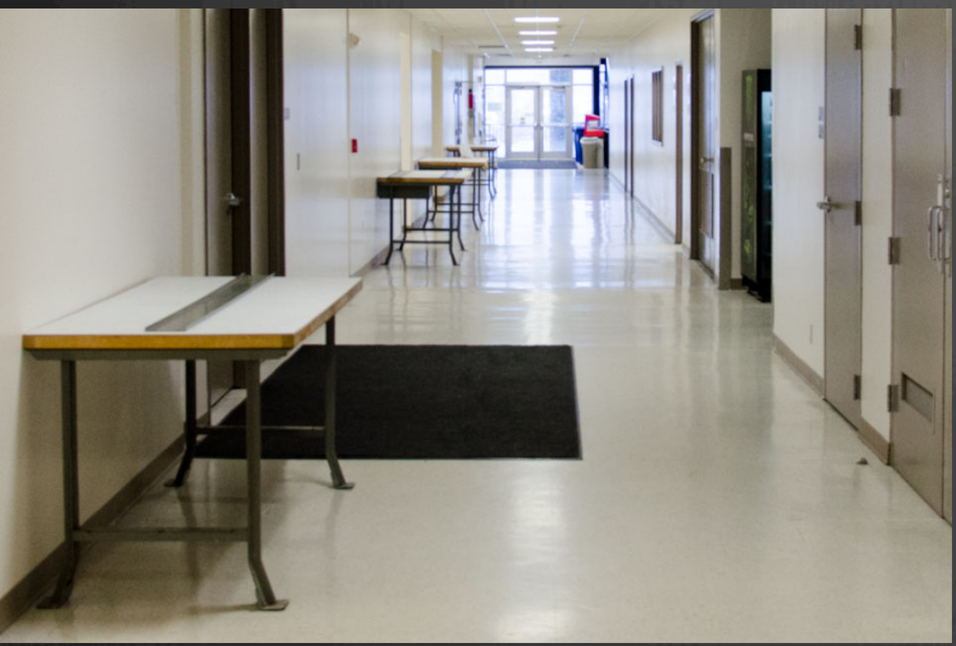


Predicted visibility of geometry under *profound* low vision.

Note that the visibility filter can operate on any HDR or even LDR image...

Evaluation of an existing site prior to

and/or post renovation!



20/20

20/250

Future work

Identify False Positives

SGIS Staircase…

Future work

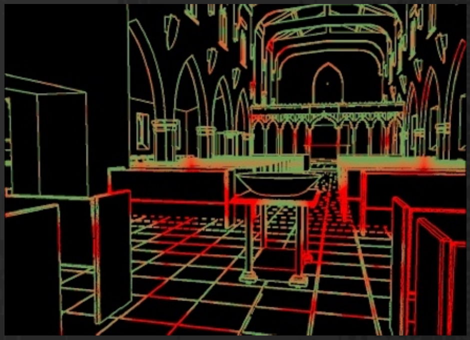
Identify False Positives

Glare: In discussion with Jan Wienold. Working on integraieng a 2^{nd} pass to identify glare

Remove non-trip surface features less that 1/2” high/wide from the walking planes in the Ground Truth edge analysis

Add visibility/luminance thresholds for dim scenes

SEEK DEVELOPERS to integrate this work into the tools such as REVIT, maybe AGI32, making it accessible to the architectural design professions



Publications and presentations

2017 2016 2015 2014 2013 2012 2011 2010 2009 2008

2017

Thompson, W.B., Legge, G.E., Kersten, D.J., Shakespeare, R.A., & Lei, Q. (2017). Simulating visibility under reduced acuity and contrast sensitivity. *Journal of the Optical Society of America A*, *34*(4). [link]

2016

Barhorst-Cates, E.M., Rand, K. M., & Creem-Regehr, S.H. (2016). The effects of restricted peripheral field-of-view on spatial learning while navigating. *PLoS One*, *11*(10). [link]

Chung, S.T.L. & Legge G.E. (2016). Comparing the shape of contrast sensitivity functions for normal and low vision. *Investigative Ophthalmology & Visual Science*, *57*(1). [link]

Legge, G.E., Gage, R., Baek, Y., & Bochsler, T.M. (2016). Indoor spatial updating with reduced visual information. *PLoS ONE*, *11*(3). [link]

2015

Barhorst, E.M., Rand, K.M., Thompson, W.B., & Creem-Regehr, S.H. (2015). The effects of restricted field of view on spatial learning while navigating. Talk presented at the Rocky Mountain APA meeting, Boise, ID.

Barhorst, E. M., Rand, K. M., Thompson, W. B., & Creem-Regehr, S. H. (2015). The effects of restricted peripheral field on spatial learning while navigating. Poster presented at the 55th Annual Meeting of the Psychonomics Society, Chicago, IL.

Legge G.E. (2015). The visual accessibility of indoor spaces. Findings from low vision and restricted normal vision. Mini Symposium on “How Real is Simulated Vision Loss?”, ARVO, May 6.

Rand, K.M., Creem-Regehr, S.H., & Thompson, W.B. (2015). Spatial learning while navigating with severely degraded viewing: The role of attention and mobility monitoring. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(3). [PubMed abstract]

Rand, K. M., Barhorst, E. M., Thompson, W. B., & Creem-Regehr, S. H. (2015, November). Estimates of distance traveled while walking with normal compared to degraded vision. Poster presented at the 55th Annual Meeting of the Psychonomics Society, Chicago, IL.

16th Annual International Radiance Workshop

A Validated Approach to Predicting Visibility + Thank You!

Designing Visually Accessible Spaces
NIH Grant 2 ROI EY017835-06A1

Rob Shakespeare
Indiana University PI

Other research team members from:
University of Minnesota, Low Vision Lab & Computational Vision
University of Utah, Computer Science & Visual Perception & Spatial Cognition