Designing Visually Accessible Spaces (DeVAS): Visibility prediction tools and introducing the Hazard Visibility Score

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Indiana University

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University of Minnesota

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DESIGNING VISUALLY ACCESSIBLE SPACES

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UNIVERSITY OF MINNESOTA

Why is Visibility Prediction Important?

Fully sighted acuity	20/20
Low vision (US definition)	20/40
Legal blindness threshold (US)	20/200
Blindness threshold (WHO)	20/400

Visual impairment less than:	2017 millions	2050 millions
Low vision	5.7	9.6
Legal blindness	1.3	2.3
Completely blind	.24	.42

Source: Chan, T., D. S. Friedman, C. Bradley and R. Massof (2018)

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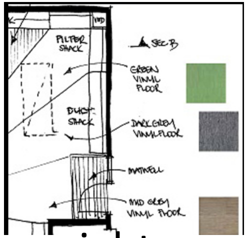
Low Vision community has visual ability
BUT we do not yet robustly include their visual needs in our environments.

DeVAS

Specific Area	General Light Reflectance Value Range [1,2,10] (See note 1)	Minimum Value Contrast at Edge (%) [2,3,4,8,10, 11] (See note 2)	Minimum Value Contrast to Adjacent or Background Surfaces [2,3,4,11] (See note 2)	Maximum Sheen (Gloss Units GU) [2,4,5,6,10] (See note 3)	Change of Texture [2,4] (See note 4)	Pattern Restriction [2,4](See note 5)	Comment [2,5,9]
Offices & Class Rooms							
Floors	20 – 50	30	30	1 – 25	YES	YES	
Walls	60 – 80	N/A	30	25 – 40	N/A	N/A	
Display Walls	N/A	N/A	30	25 – 40	N/A	N/A	
Seating	N/A	N/A	30	N/A	N/A	N/A	
Table Tops/Counters	30 – 60	30	30	10 - 25	N/A	N/A	



Interior designer might specify adjacent materials with a 30% contrast

DeVAS

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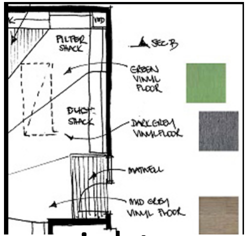

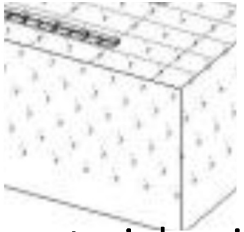

Interior designer might specify adjacent materials with a 30% contrast

Lighting designer might follow a recommended practice of 300 LUX

DeVAS

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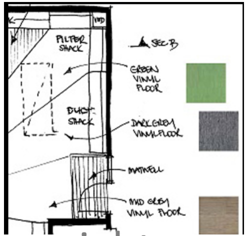
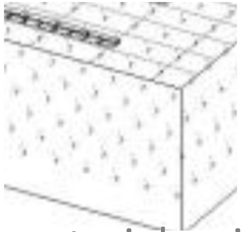
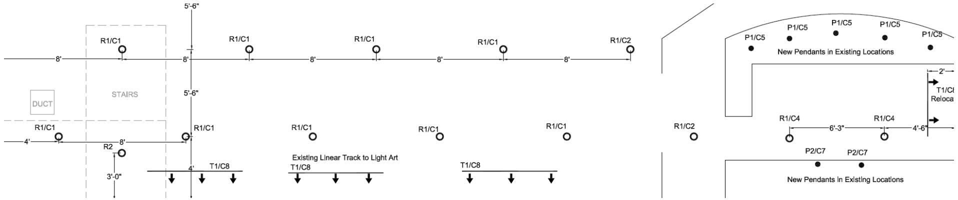




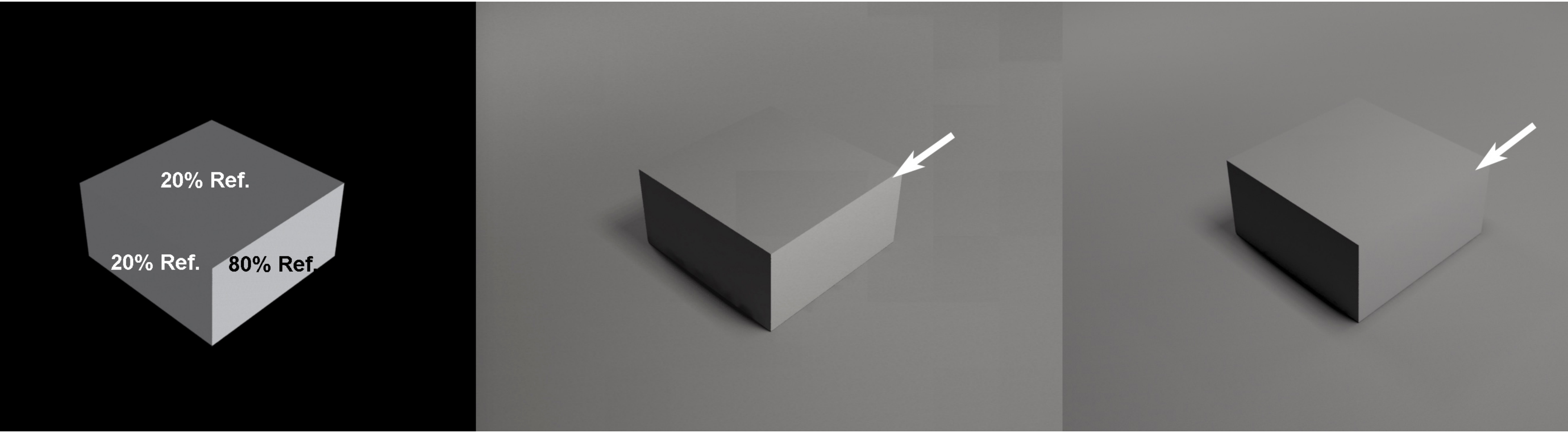
Interior designer might specify adjacent materials with a 30% contrast

Lighting designer might follow a recommended practice of 300 LUX

Typically the **impact of the lighting layout, in relationship to variations in material locations and reflectance, remains independent**.



DeVAS



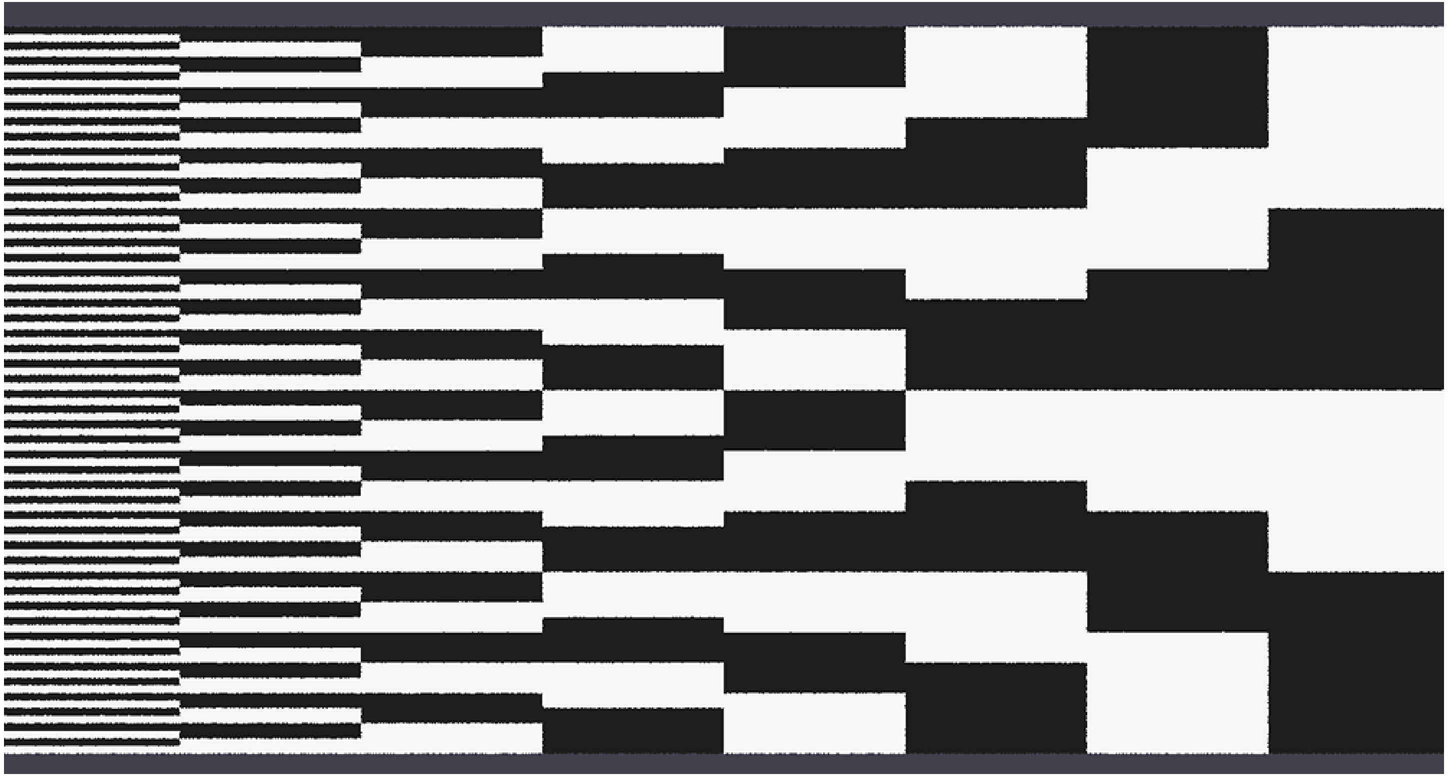
A shift in luminaire location obliterates a 60% difference in the reflectivity of these materials. Note how the edge disappears, in the right image, by moving the luminaire 2'

Design by luminance, not by illumination and material contrast specifications,
IS DESIGN BY WHAT WE SEE

Background:

Acuity and Contrast

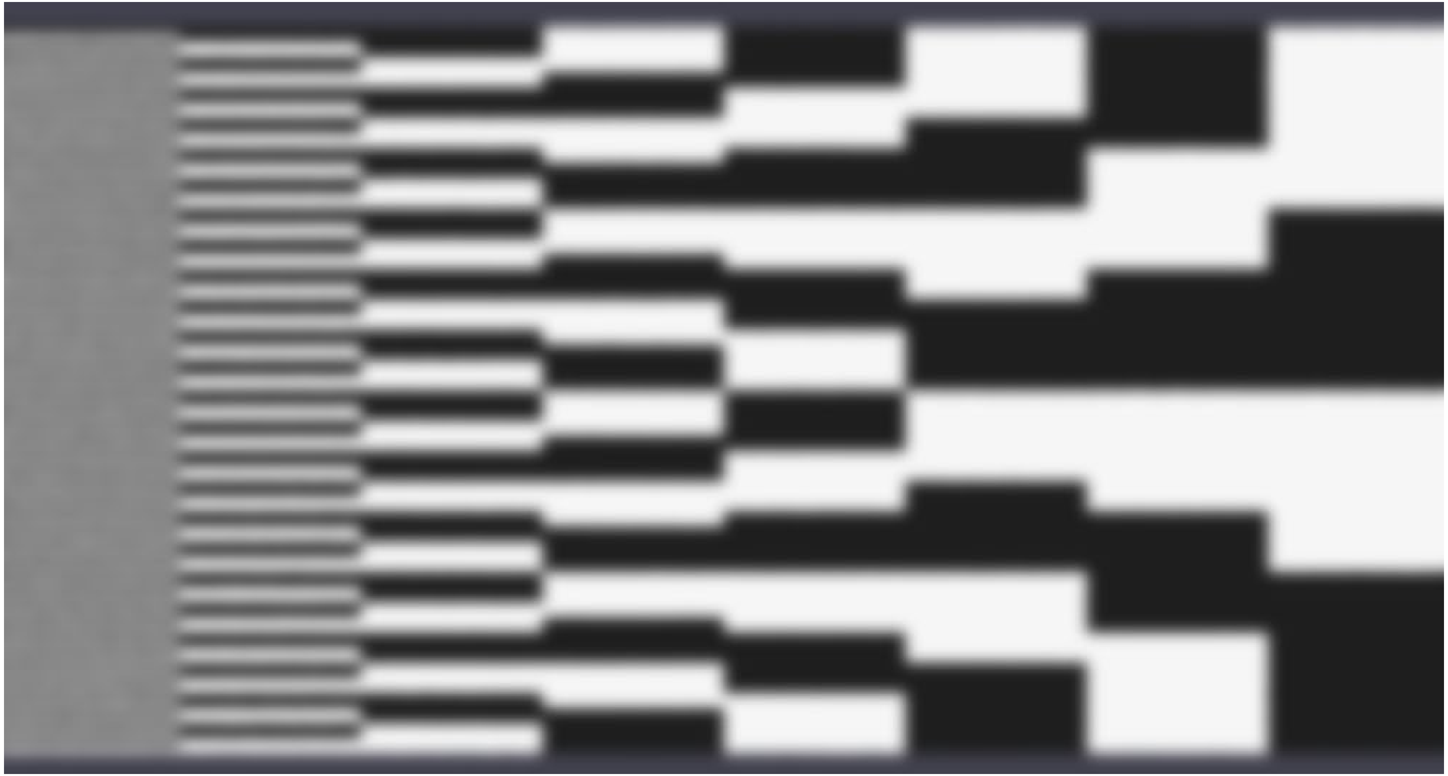
Acuity



20/20

30 cpd

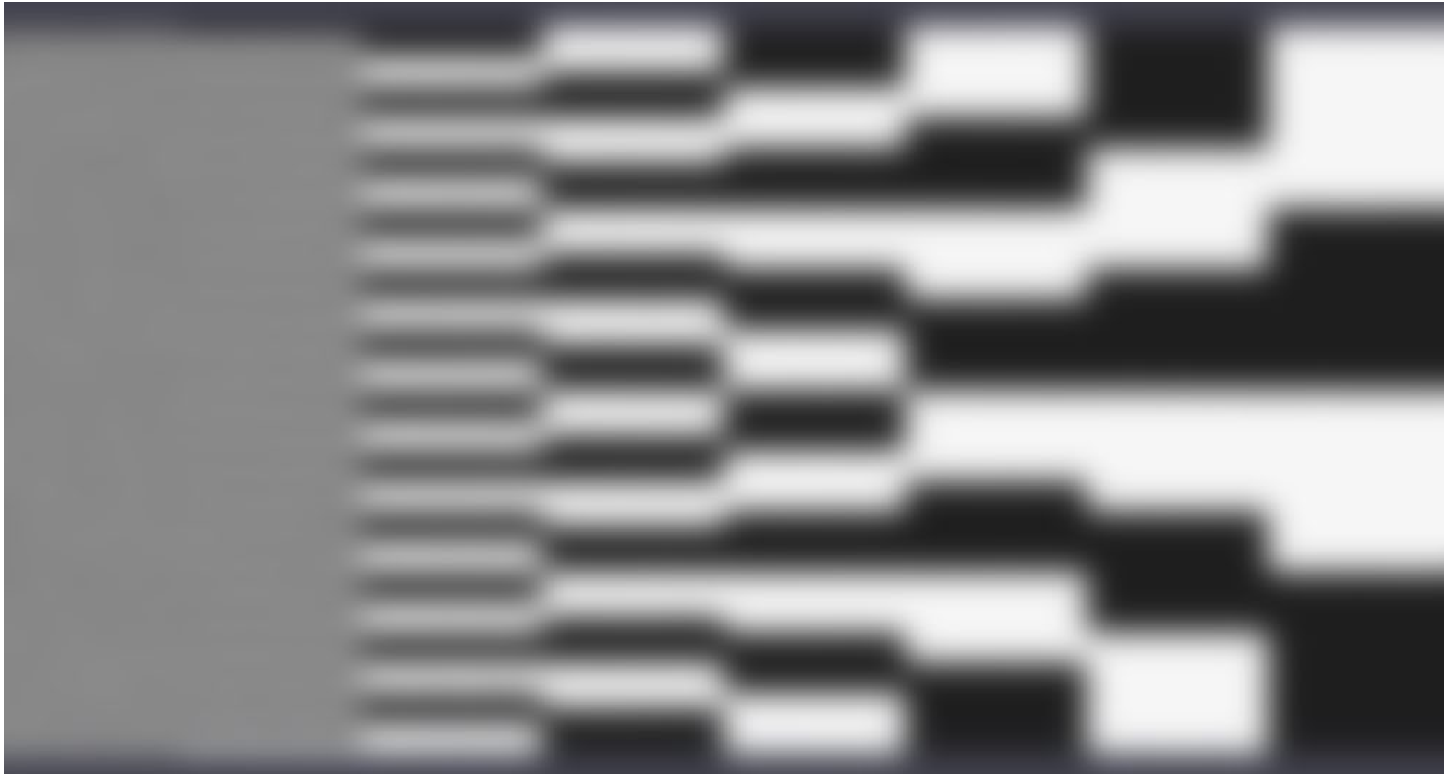
Acuity



20/40

15 cpd

Acuity



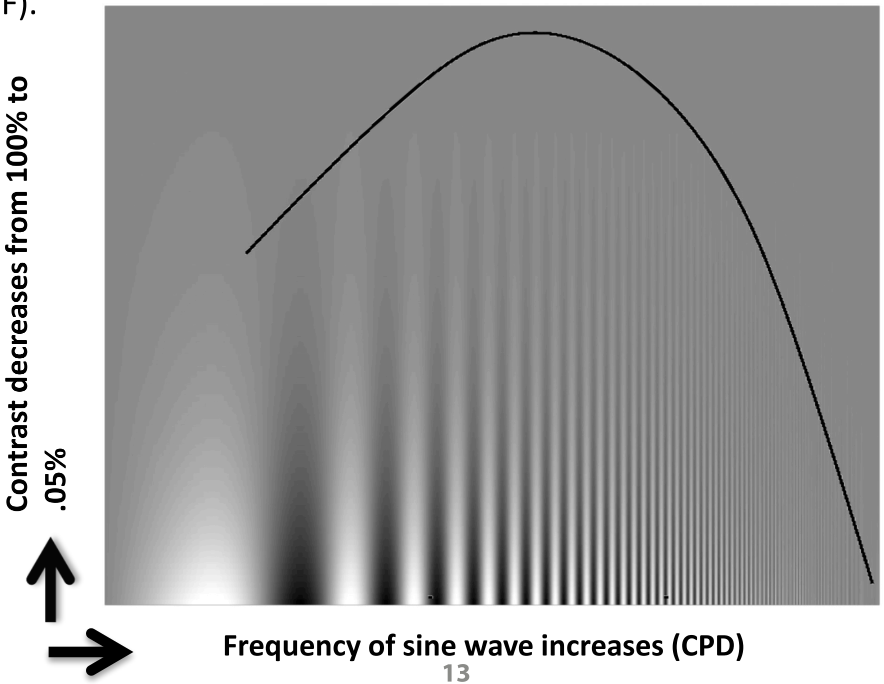
20/80

7.5 cpd

DeVAS Filter

J Opt Soc Am A Opt Image Sci Vis. 2017 April 1

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).



DeVAS Filter

J Opt Soc Am A Opt Image Sci Vis. 2017 April 1

(Thompson, Legge, Kersten, Shakespeare, Lei)

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

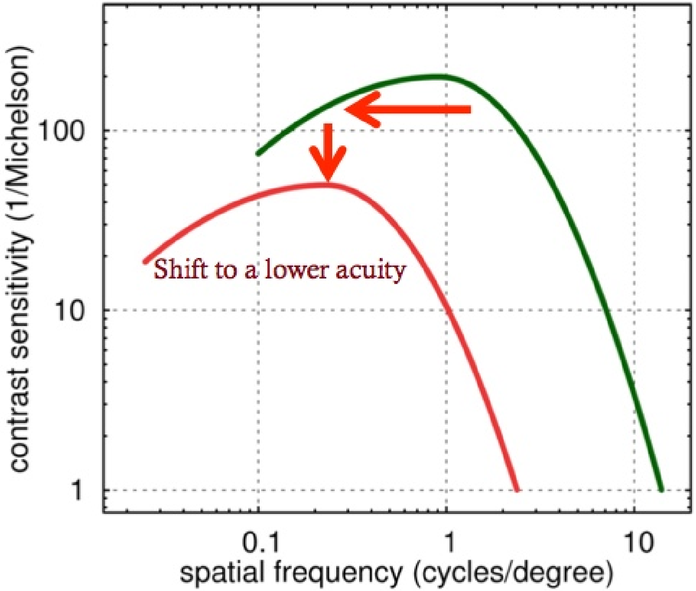
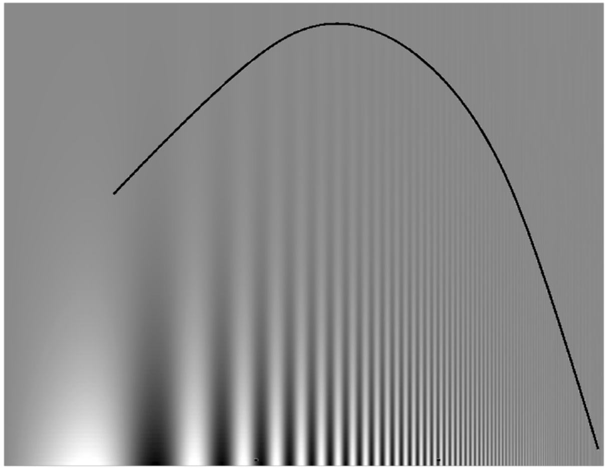
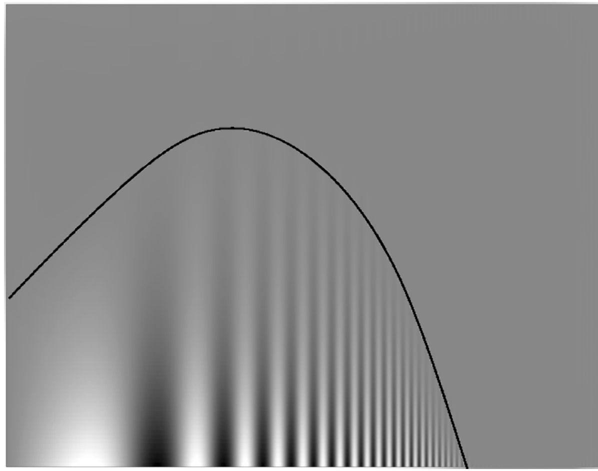


Fig. 1.
The Chung & Legge [15] CSF is an asymmetric parabola when plotted in $f_l - S_l$ space. The plotted values show two instances of the CSF, one shifted left (lower acuity) and down (lower contrast sensitivity) compared to the other.



Normal Vision CFS



A Low Vision CSF

DeVAS Filter

J Opt Soc Am A Opt Image Sci Vis. 2017 April 1

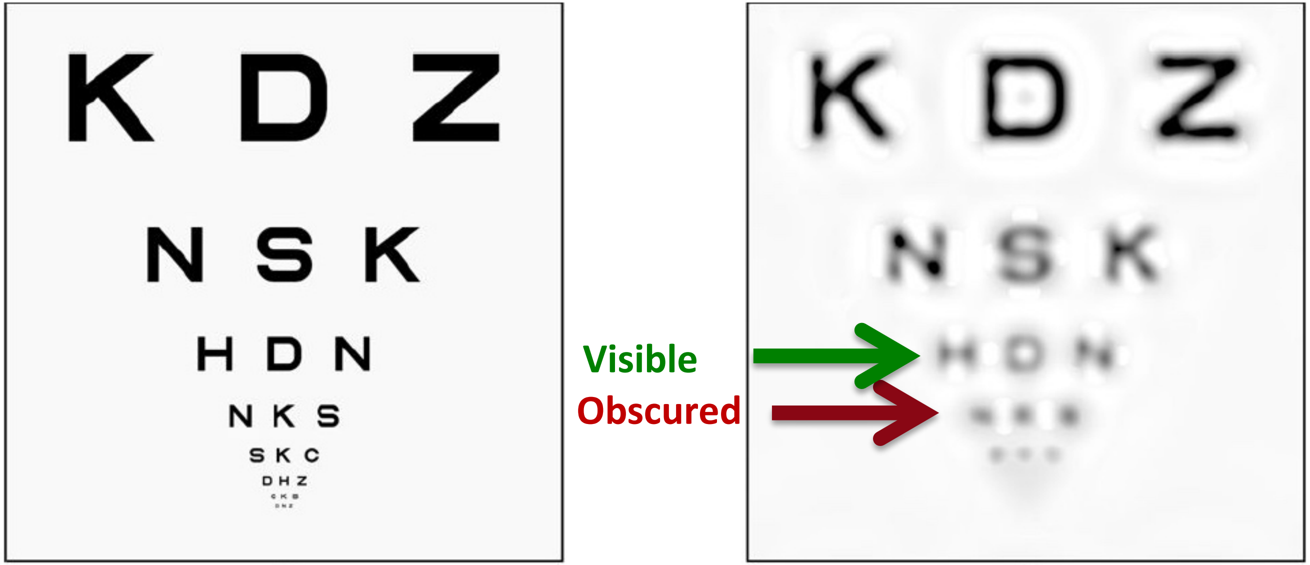
When the **DeVAS-Filter** is applied with a specific acuity to a high dynamic range image

Removes image details predicted to be not visible,

while leaving intact, details predicted to BE visible.

DeVAS Filter

J Opt Soc Am A Opt Image Sci Vis. 2017 April 1

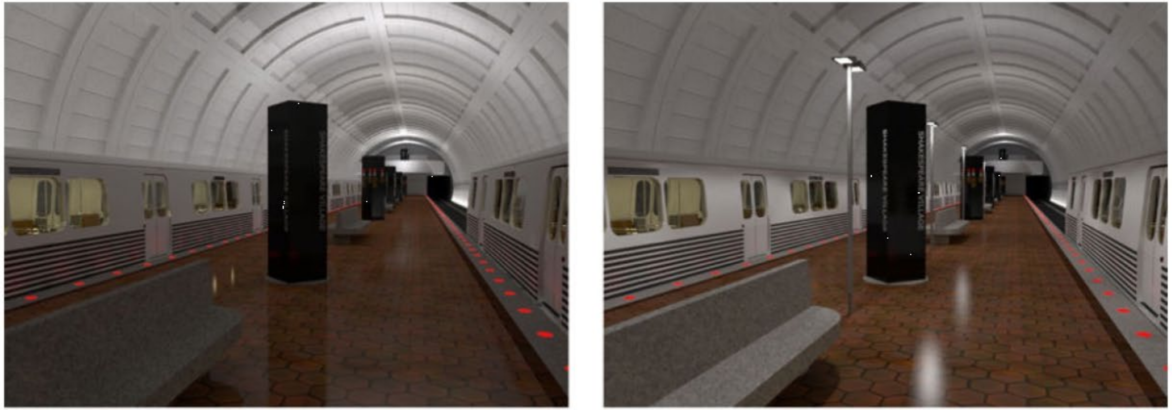


(Legally Blind: 20/200 or less with best possible correction)

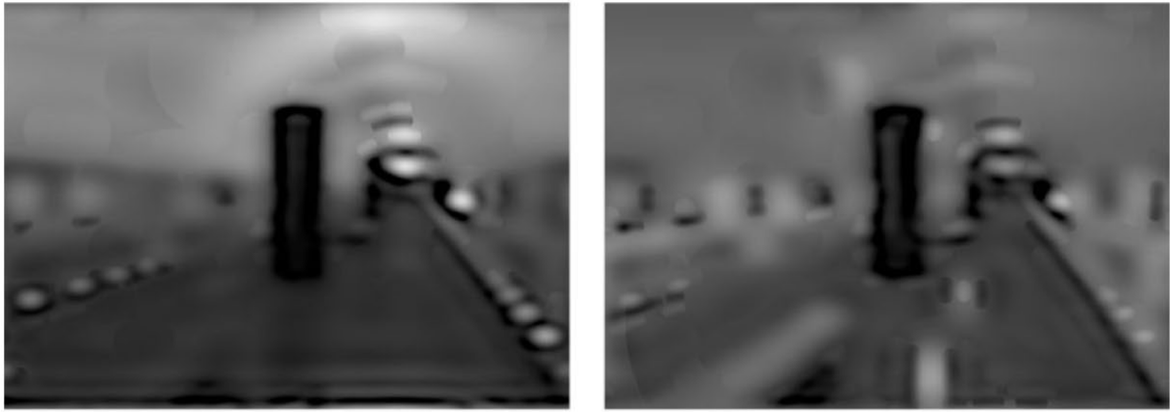
Fig. 8.
(a) Original logMAR chart, with third line from top corresponding to logMAR 1.1 and the fourth line from the top corresponding to logMAR 0.9. For correct character size, view the chart from a distance equivalent to 3.33 times the width of the chart image. (b) Original logMAR chart, filtered to simulate an acuity of logMAR 1.0. The third line is readable, the fourth line is not.

DeVAS Filter

J Opt Soc Am A Opt Image Sci Vis. 2017 April 1



Original RADIANCE renderings.



Original filtered to simulate severe low vision.

DeVAS-Visibility:

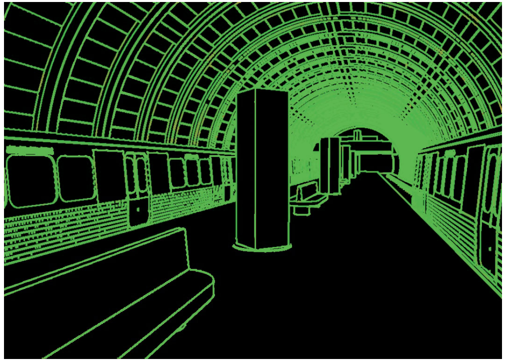
The **application tool**,

built upon **DeVAS-Filter**,

that **predicts visibility**.

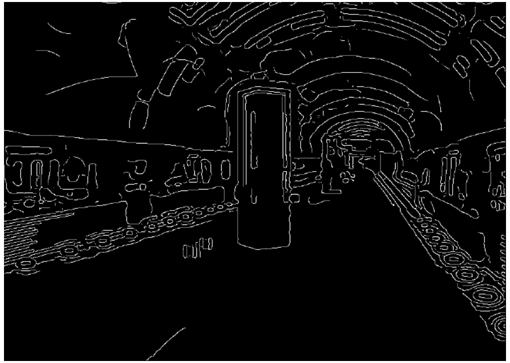
DeVAS-Visibility: Automated Visibility Prediction Application

Radiance Rendering
plus Geometry Data
New: **rtpict**



Ground Truth Edges

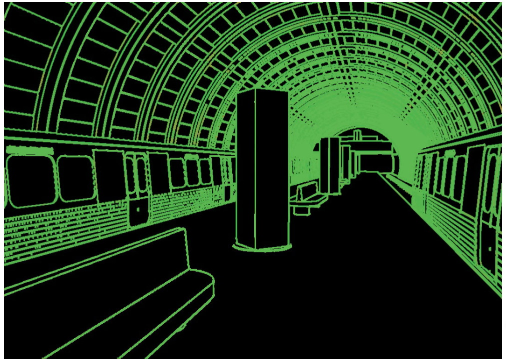
DeVAS-Filter:
Severe Low Vision



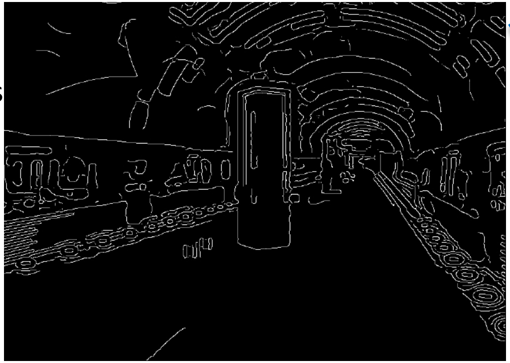
Luminance Boundaries:
Canny Edges

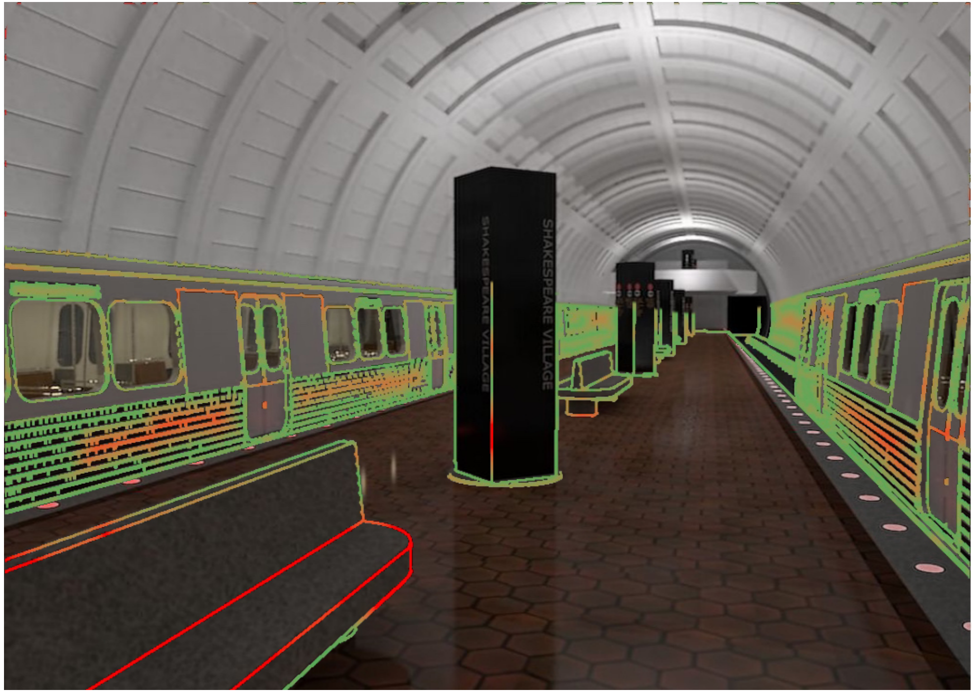
DeVAS Visibility

Ground Truth Edges



Luminance Boundaries
Severe Low Vision





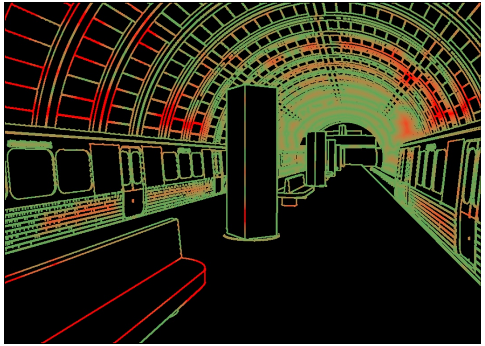
RED edges predicted **NOT** to be **visible**
Green edges predicted **visible** for Severe LV

Subjective or Objective

Judge what is likely
not visible ?

DeVAS-Filter

Automated visibility
Analysis ?

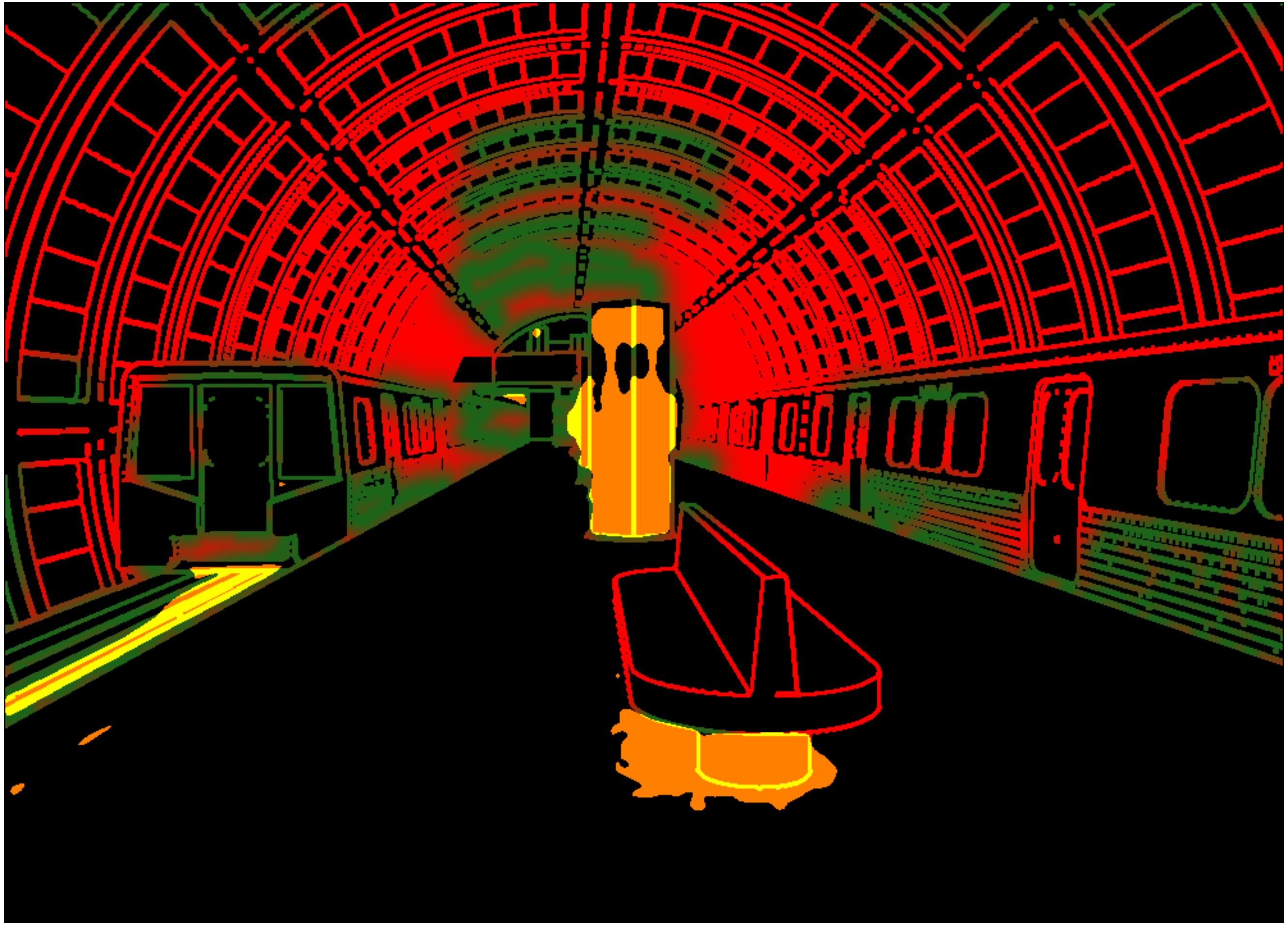


DeVAS-Visibility

DeVAS Visibility

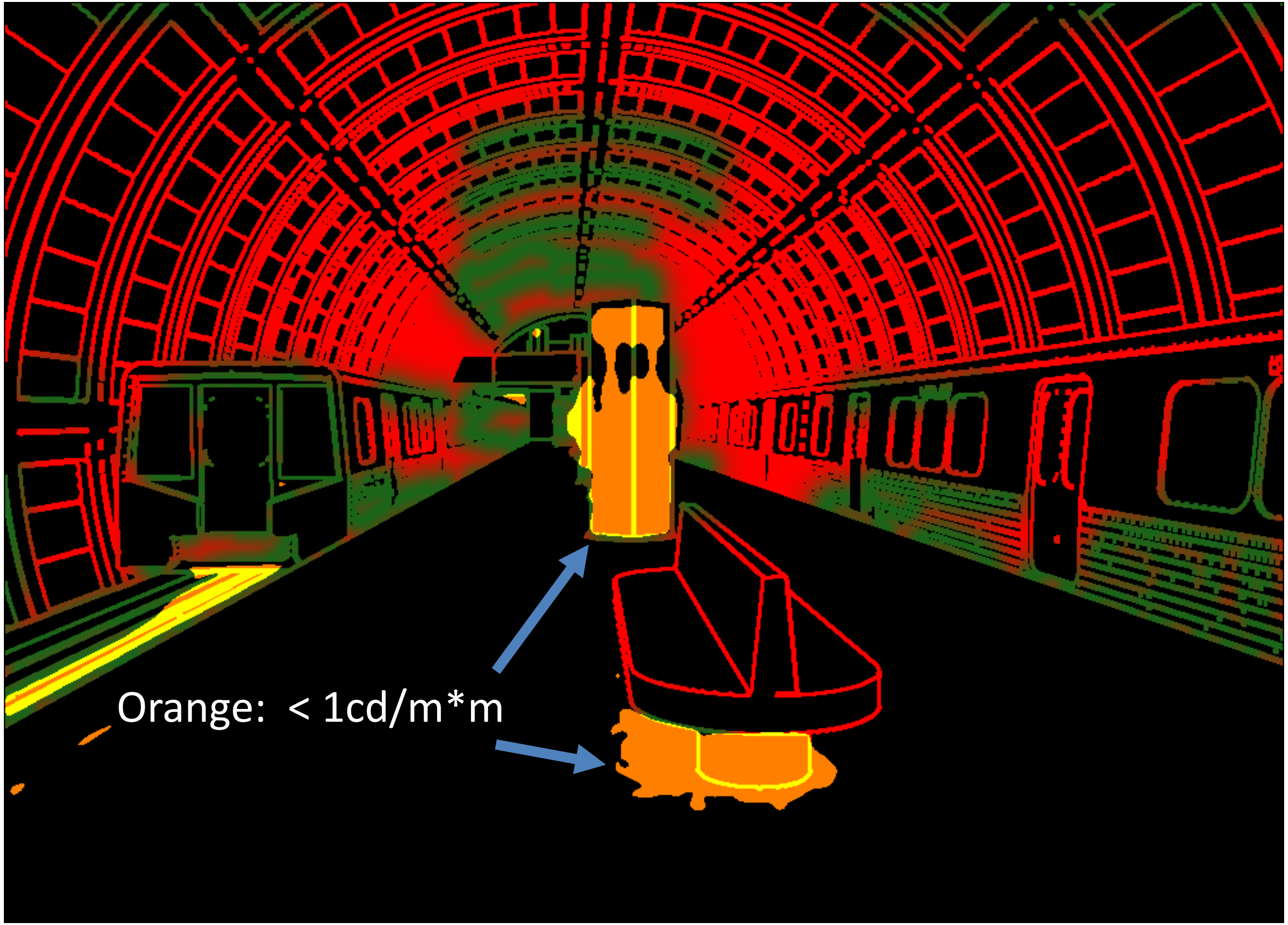
DeVAS Visibility Workflow Examples

DeVAS Visibility



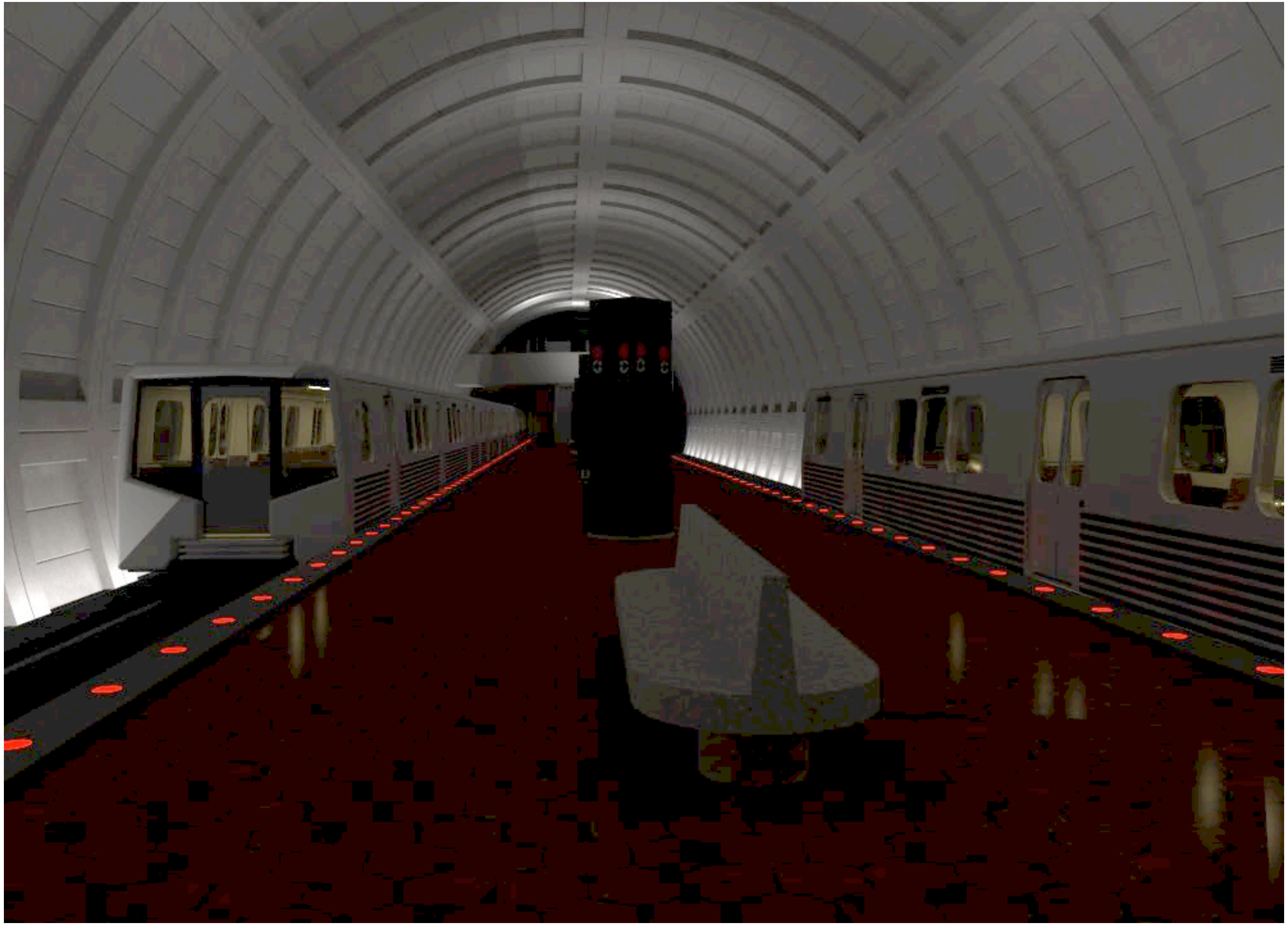
Low Vision: Severe

DeVAS Visibility



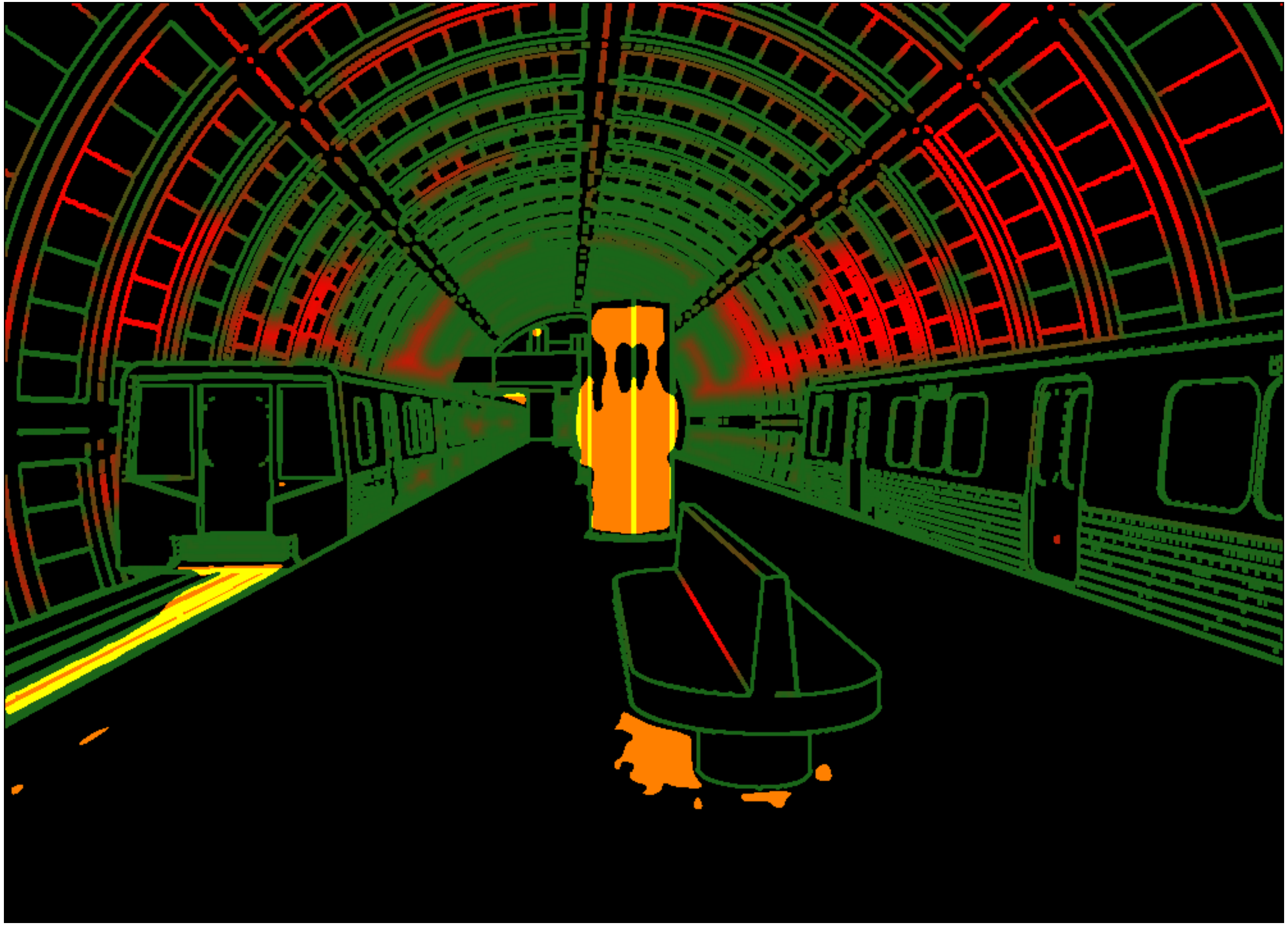
Low Vision: Severe

DeVAS Visibility



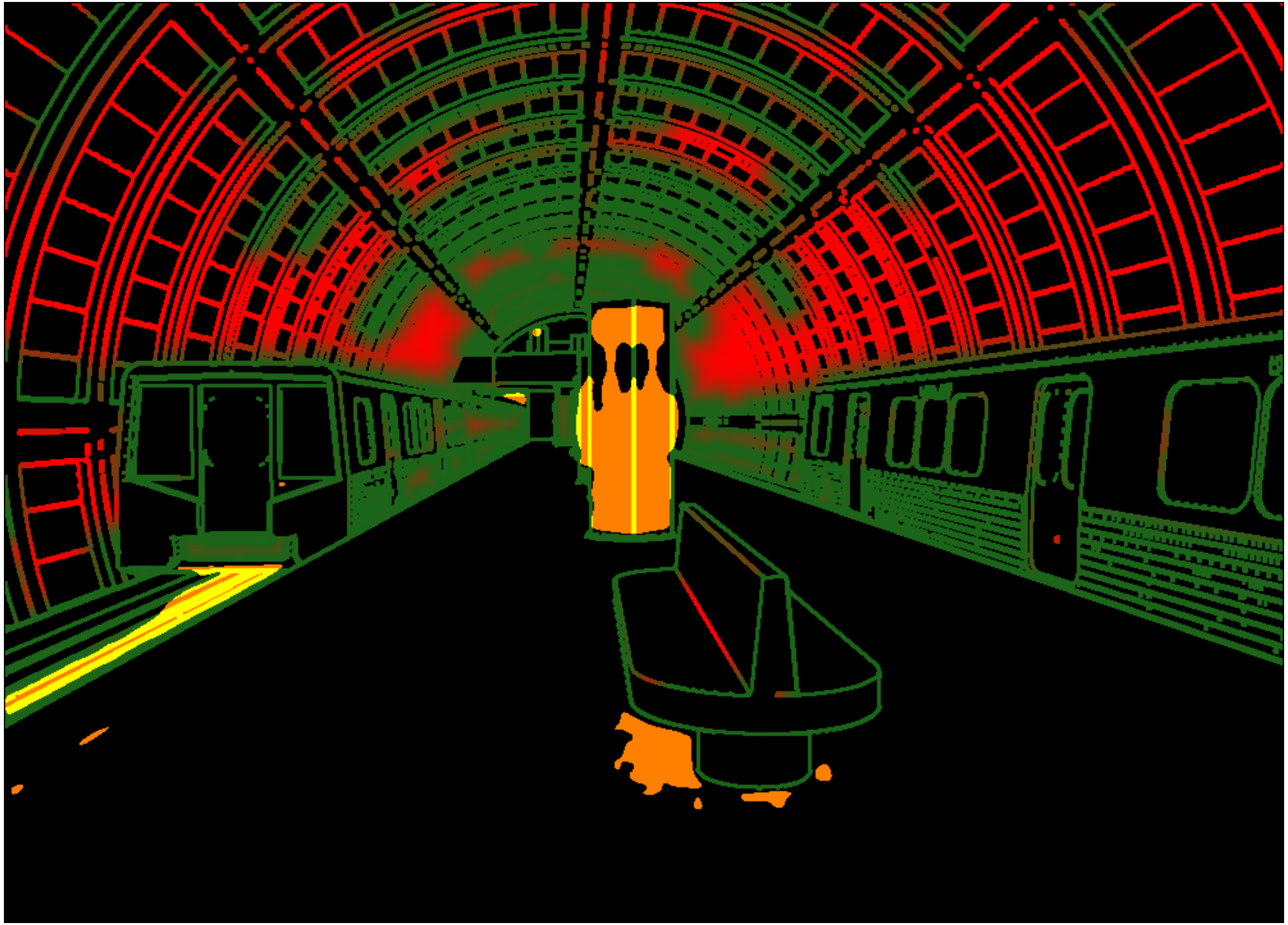
Change bench material

DeVAS Visibility



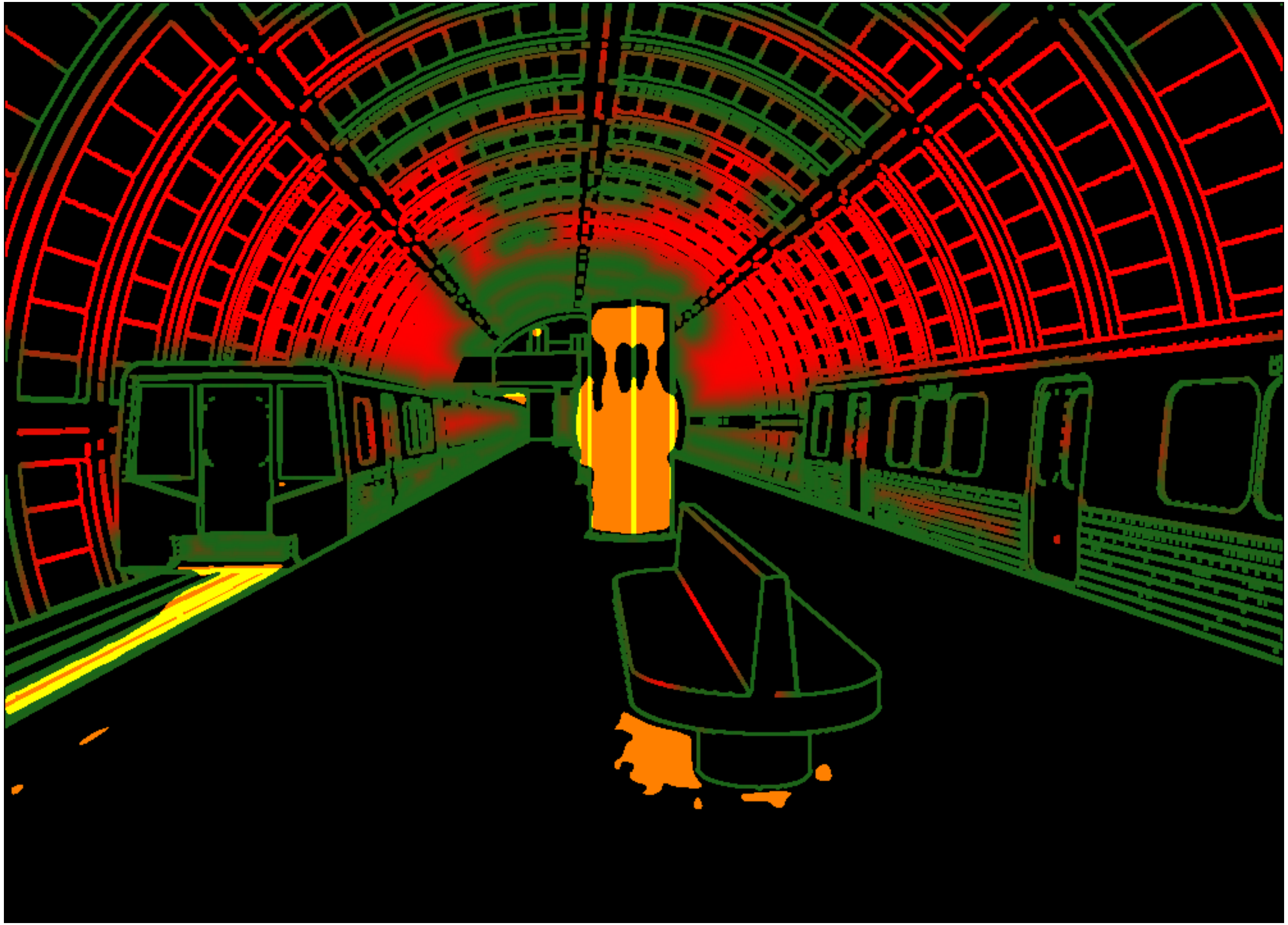
Low Vision: Mild

DeVAS Visibility



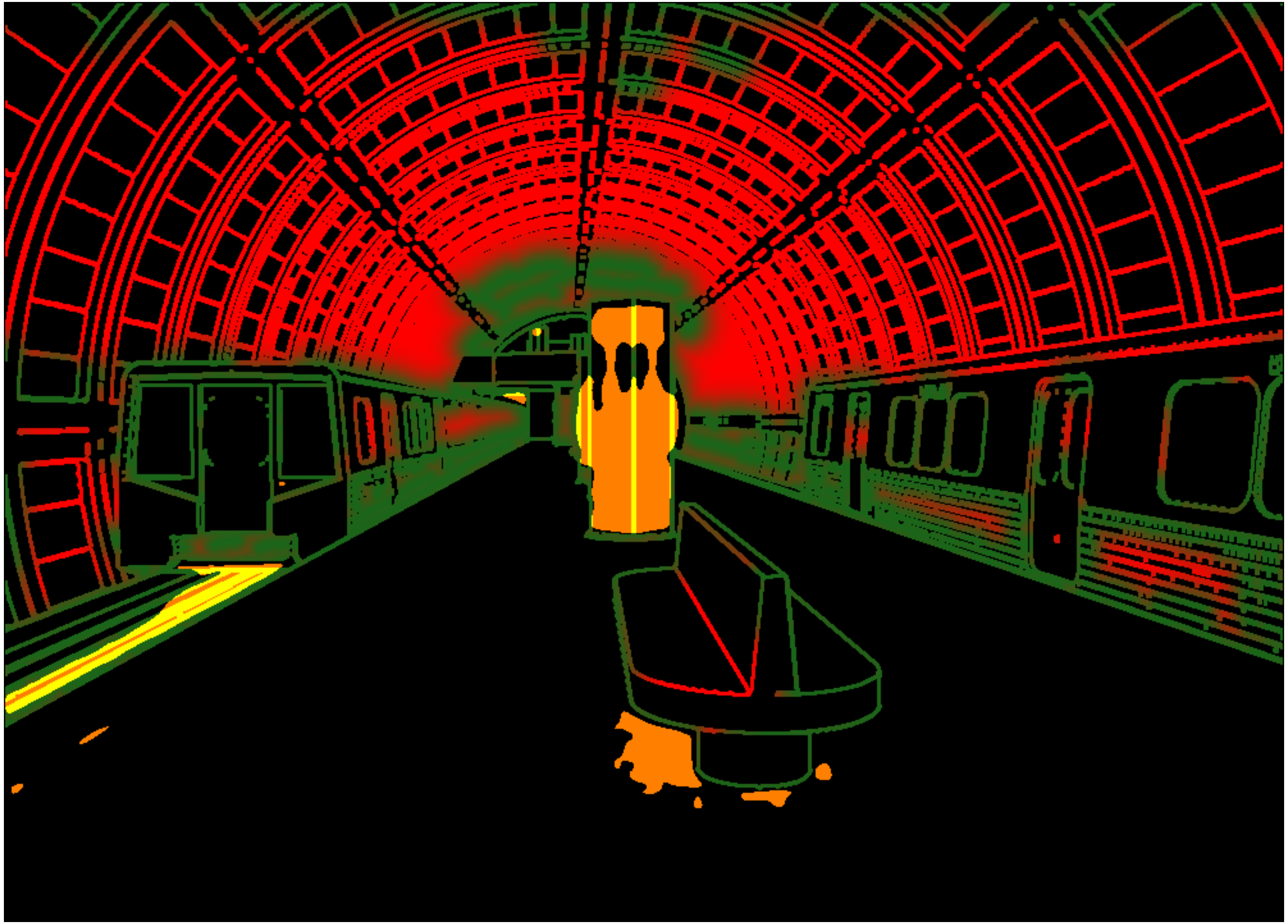
Low Vision: Moderate

DeVAS Visibility



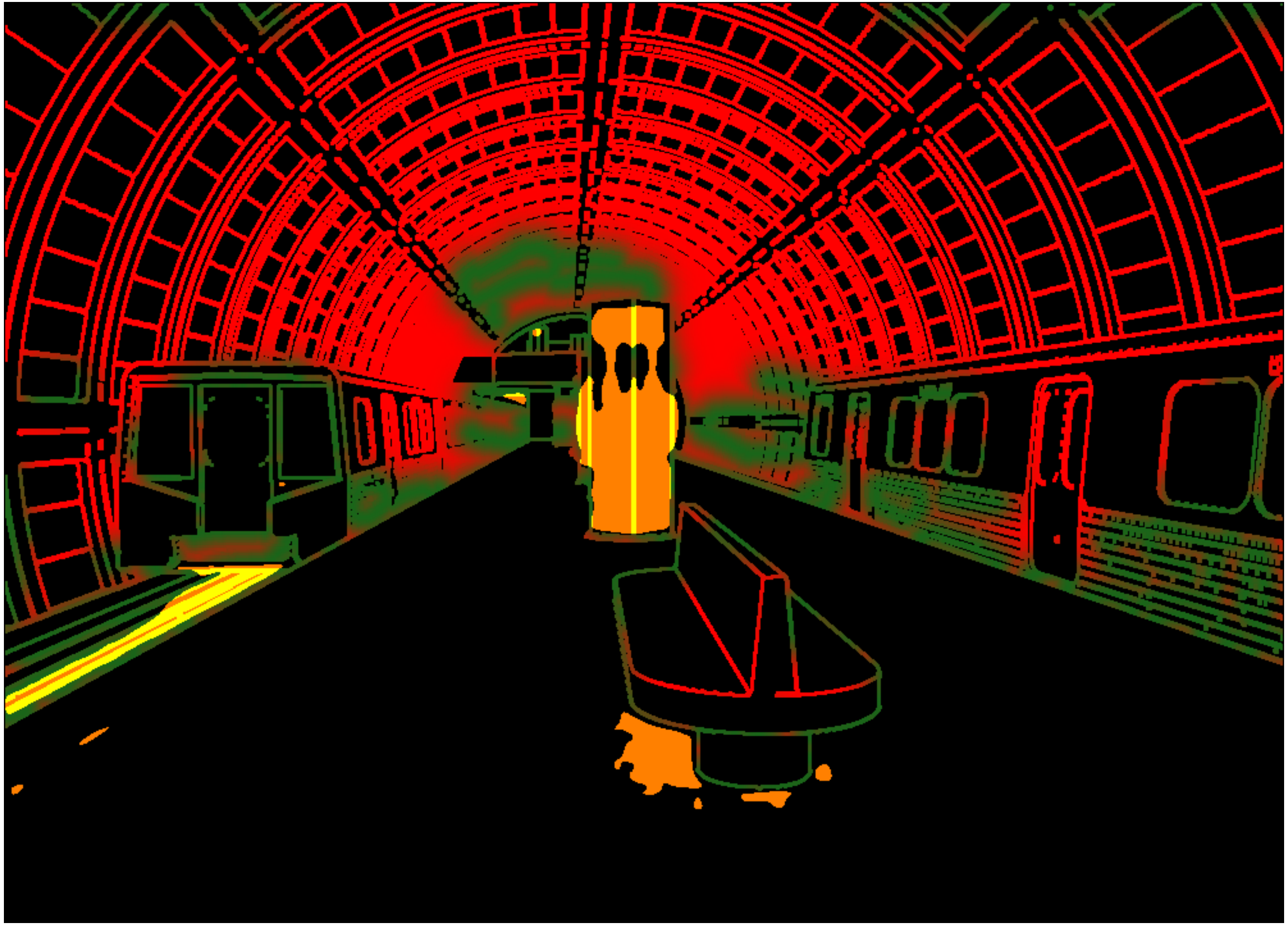
Low Vision: Legally Blind Threshold

DeVAS Visibility



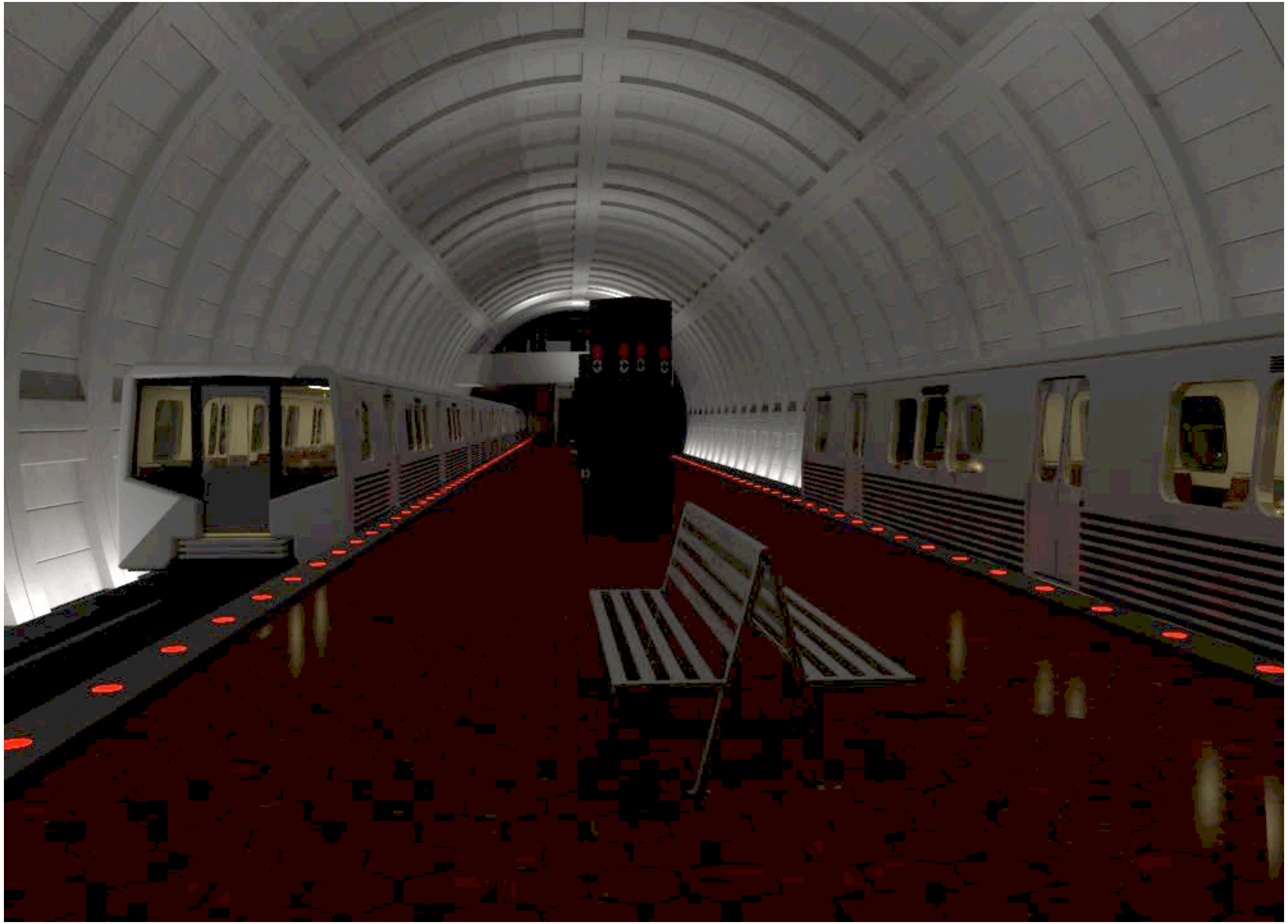
Low Vision: Severe

DeVAS Visibility



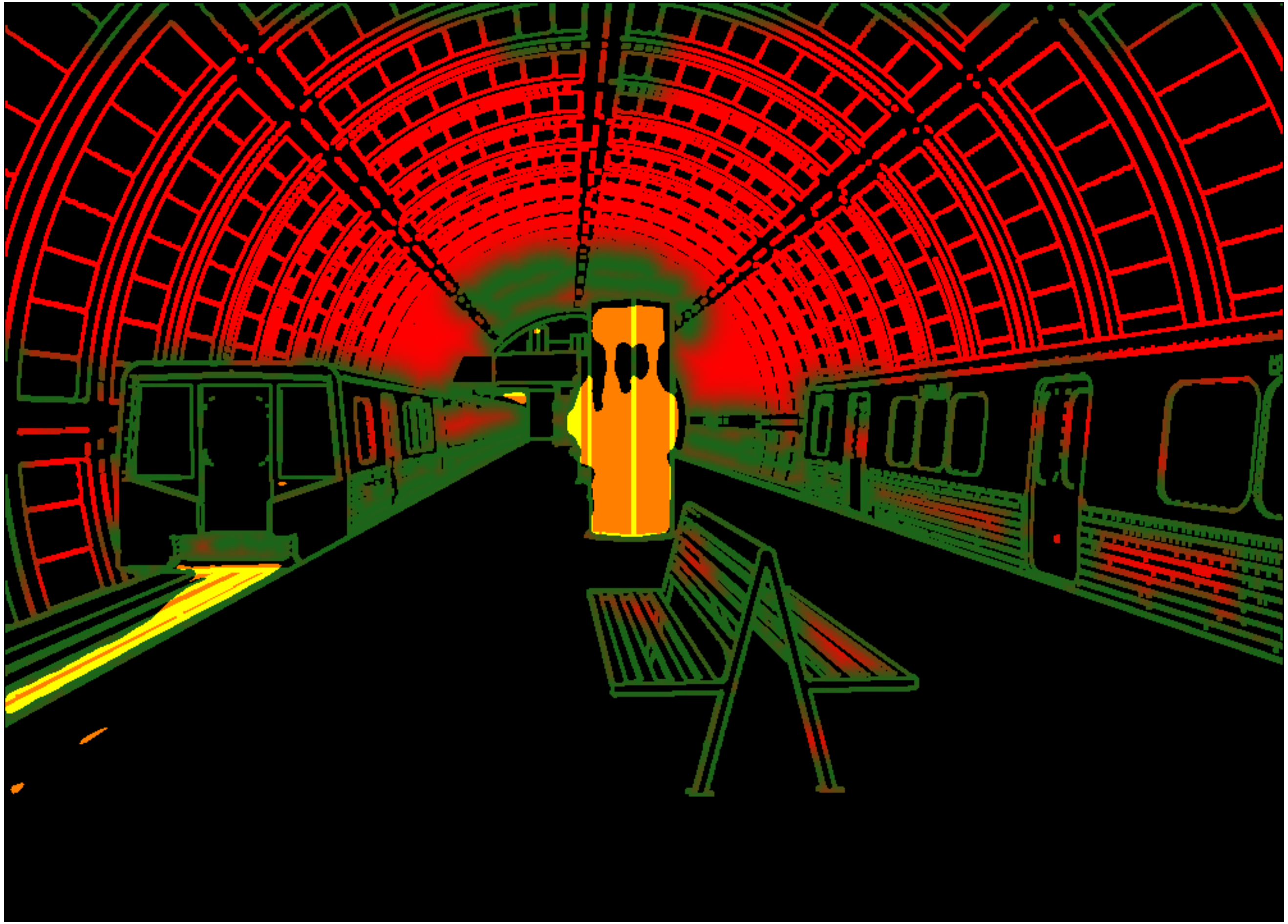
Low Vision: Profound

DeVAS Visibility



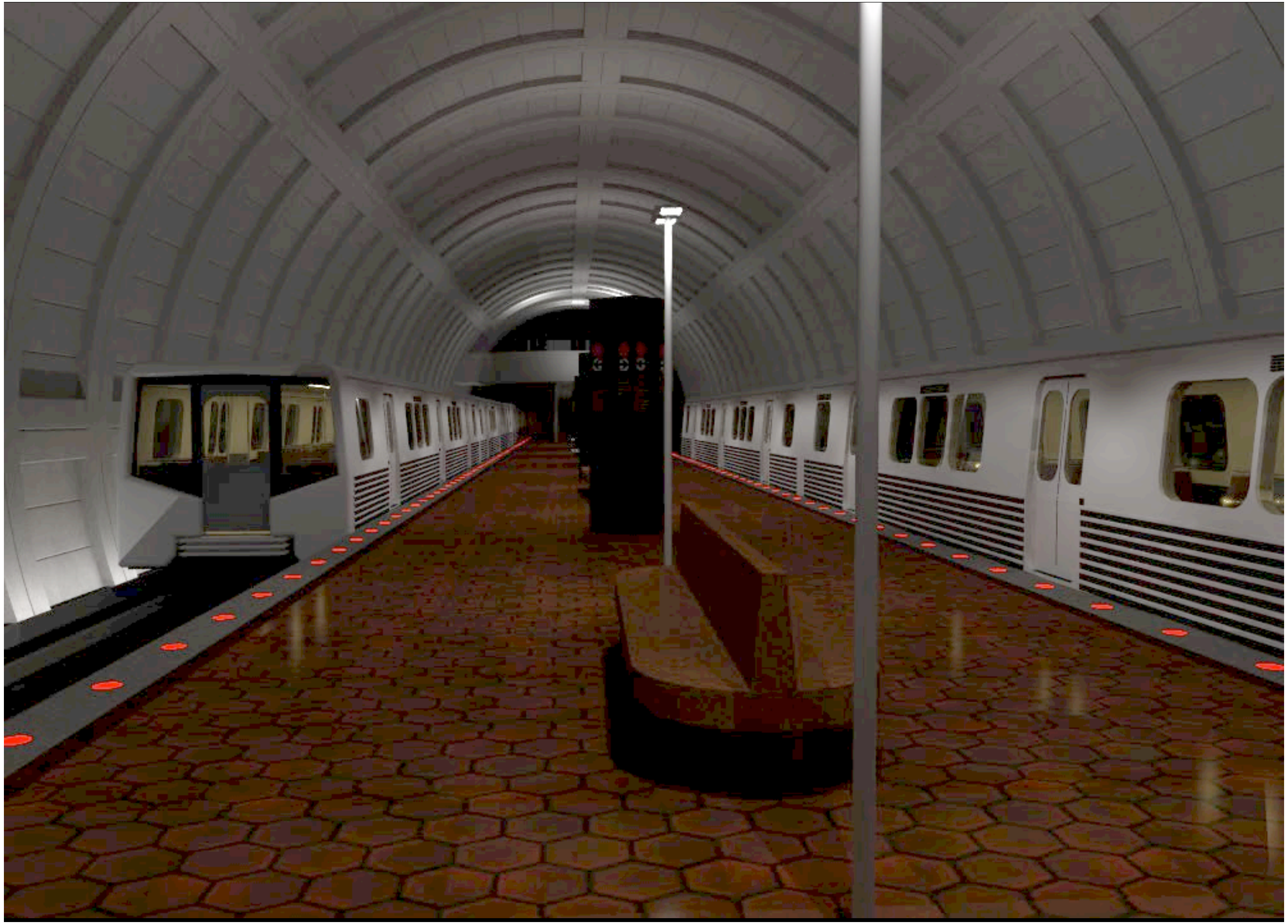
Change the bench type and material

DeVAS Visibility



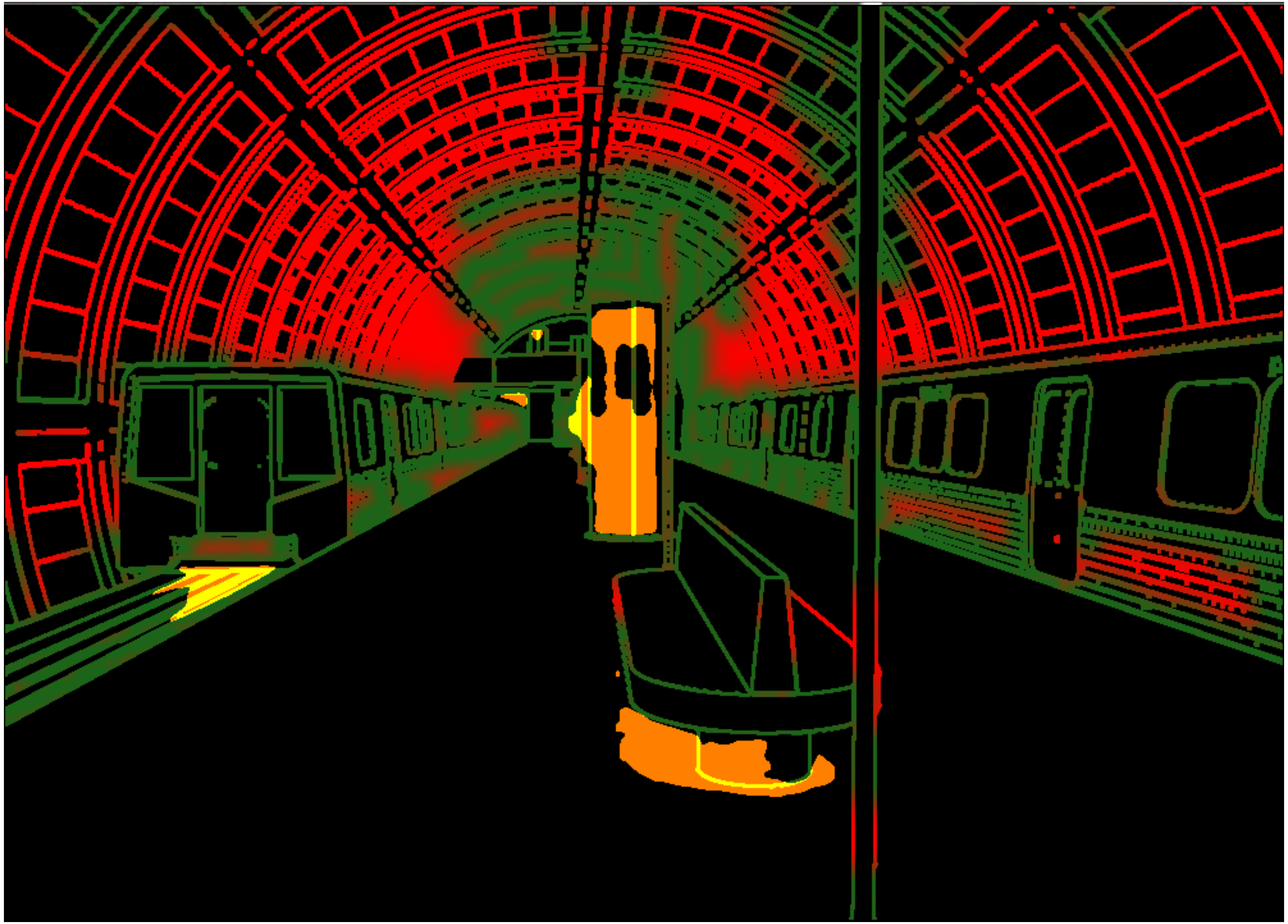
Low Vision: Severe

DeVAS Visibility



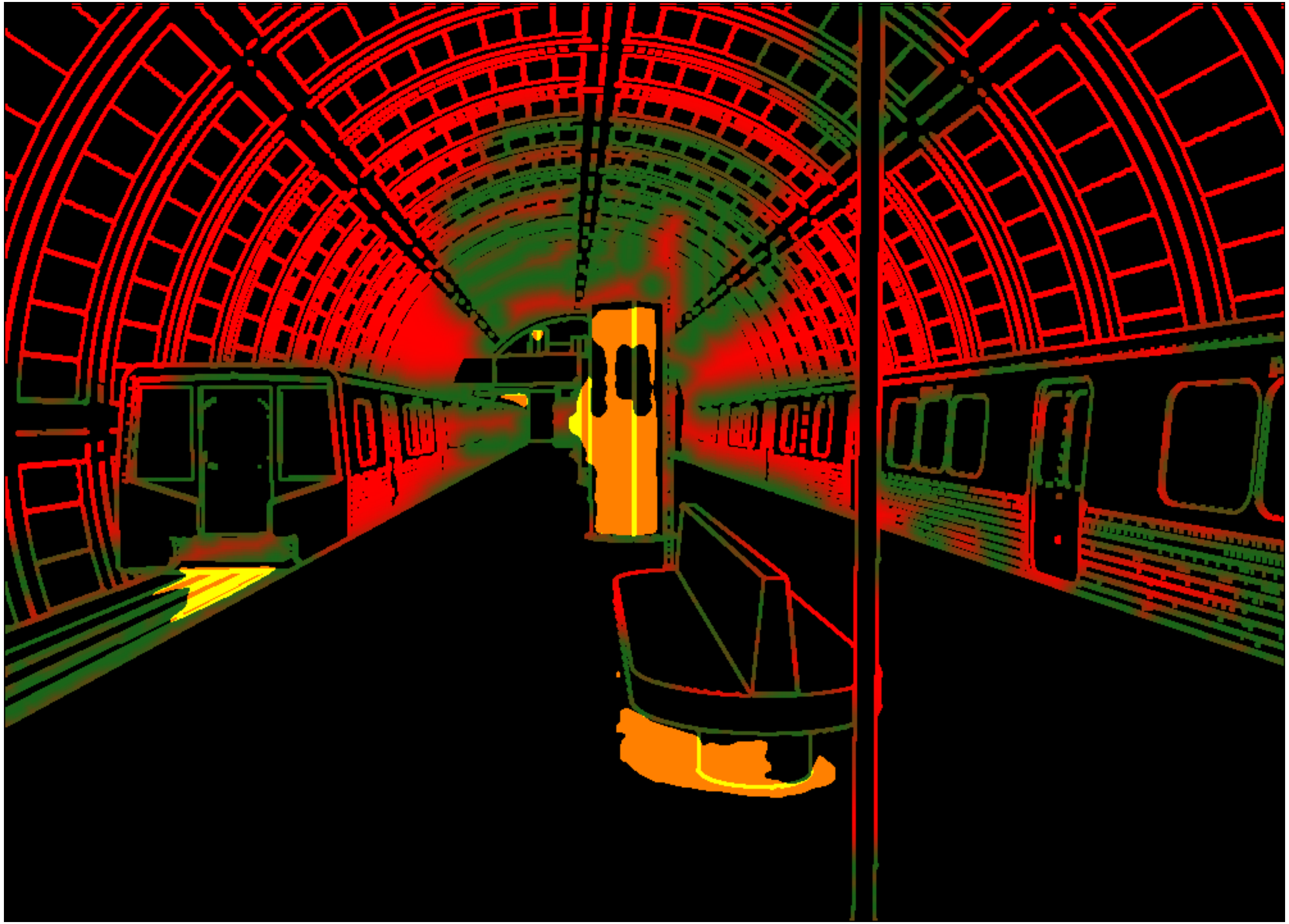
Change the illumination

DeVAS Visibility



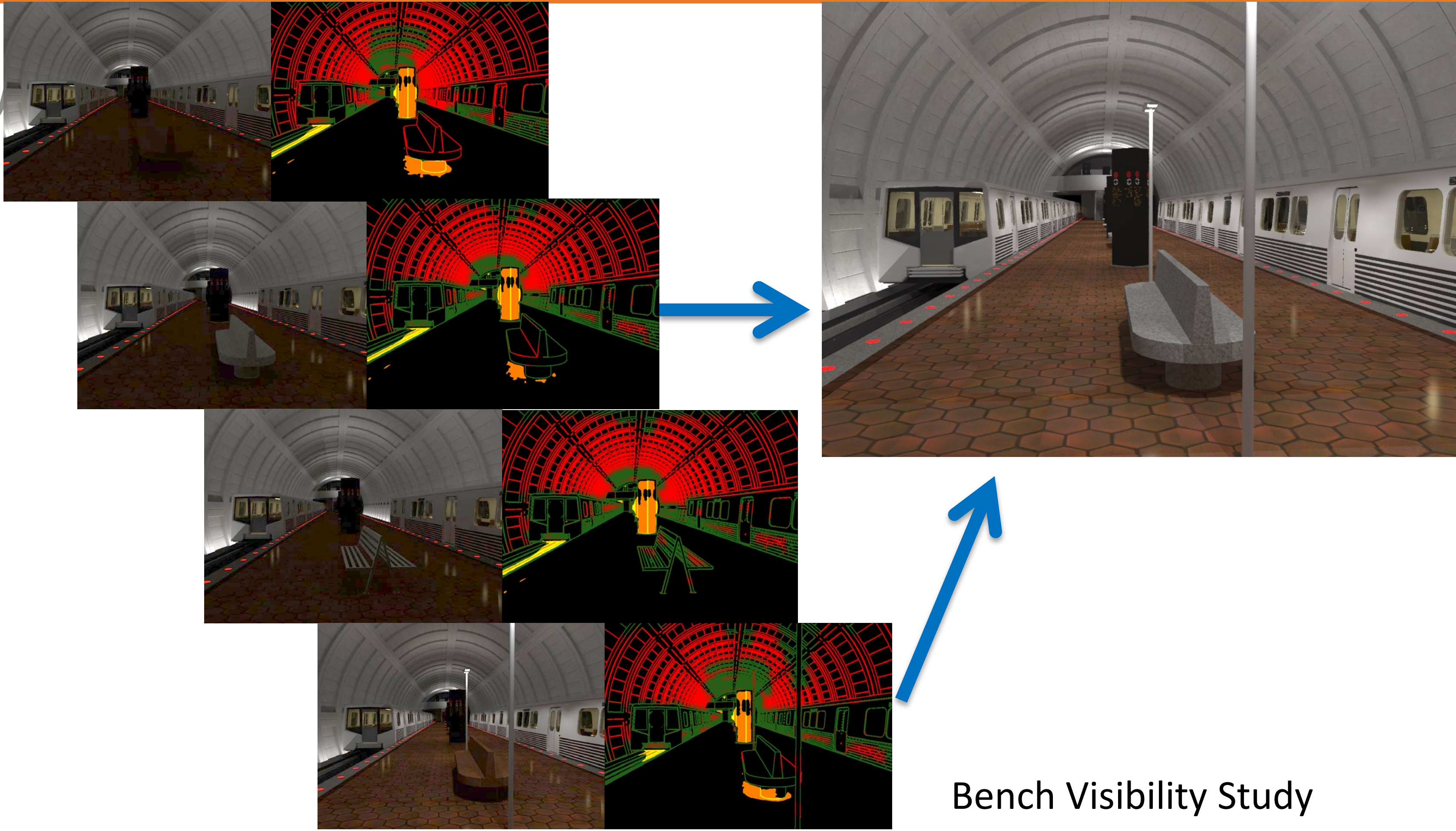
Low Vision: Severe

DeVAS Visibility



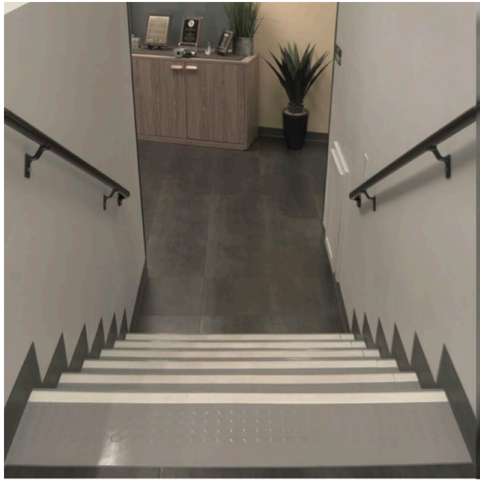
Low Vision: Profound

DeVAS Visibility



Bench Visibility Study

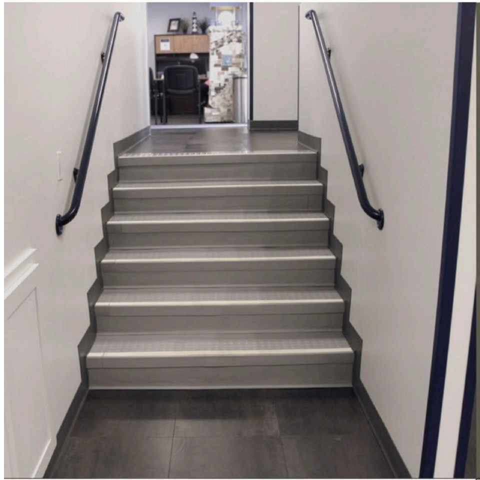
DeVAS Steps Study



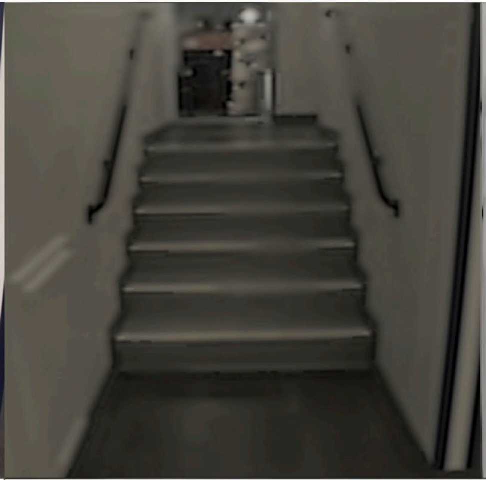
HDR Photo

Severe Filter of HDR Photo

Severe Filter of Model



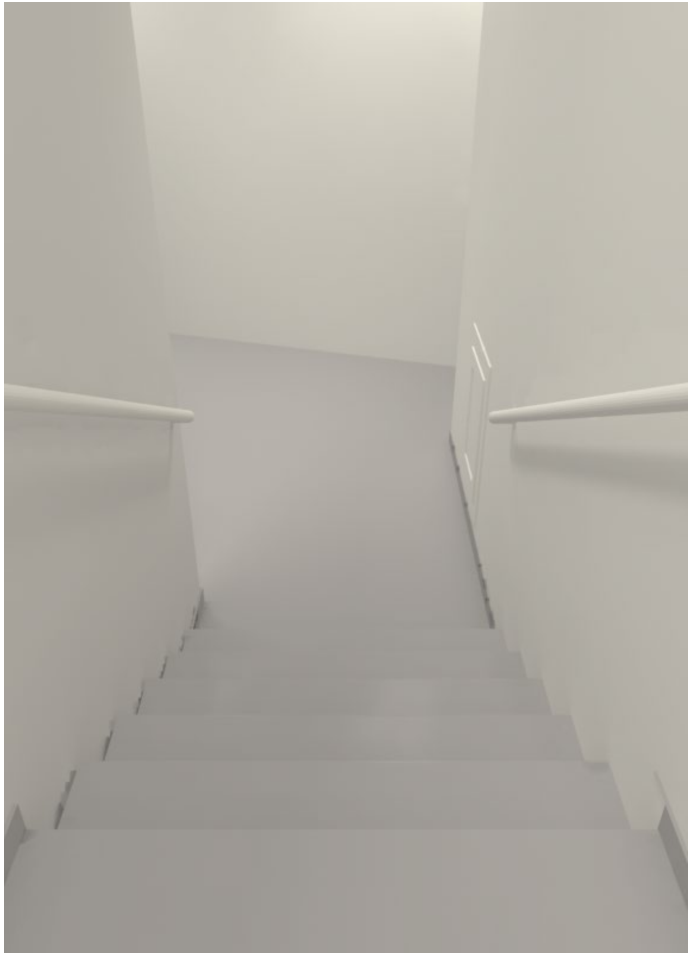
HDR Photo



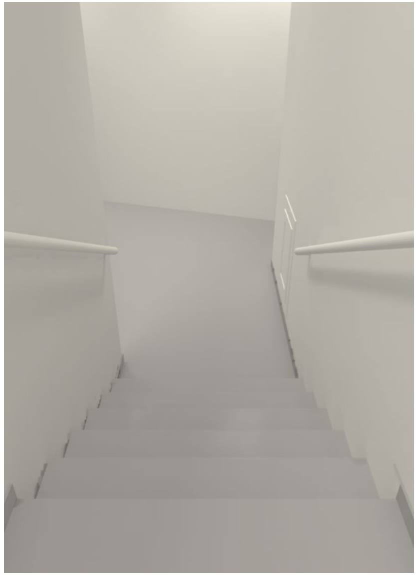
Severe Filter of HDR Photo

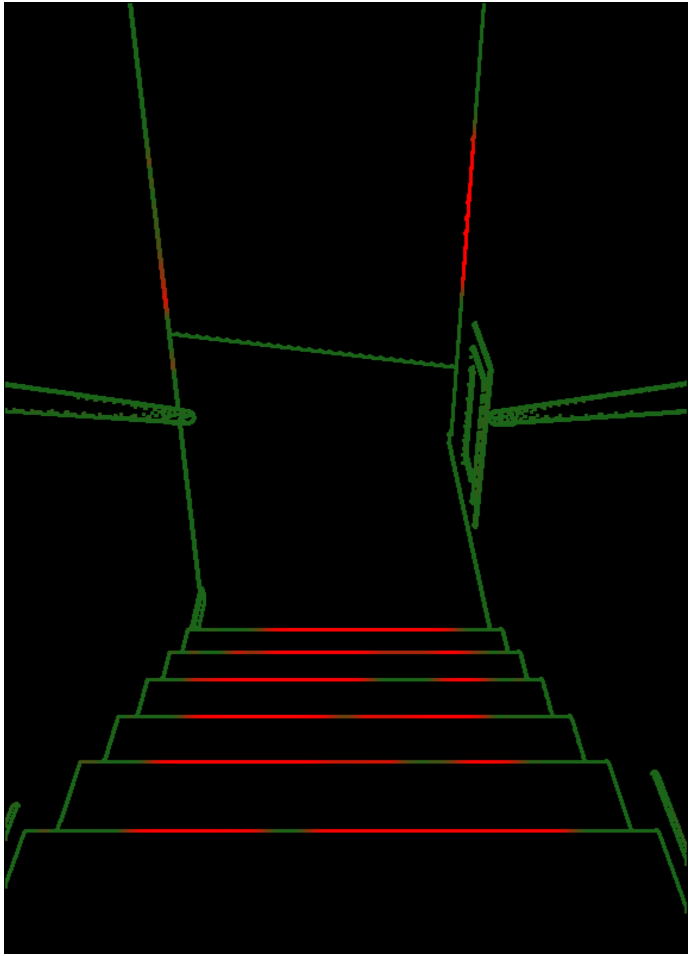
Severe Filter of Model

DeVAS
Steps Study



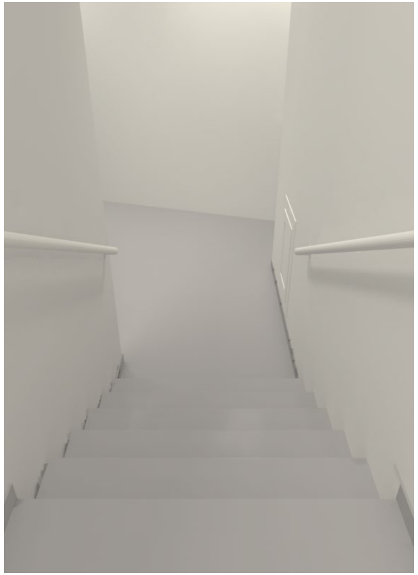
DeVAS
Steps Study

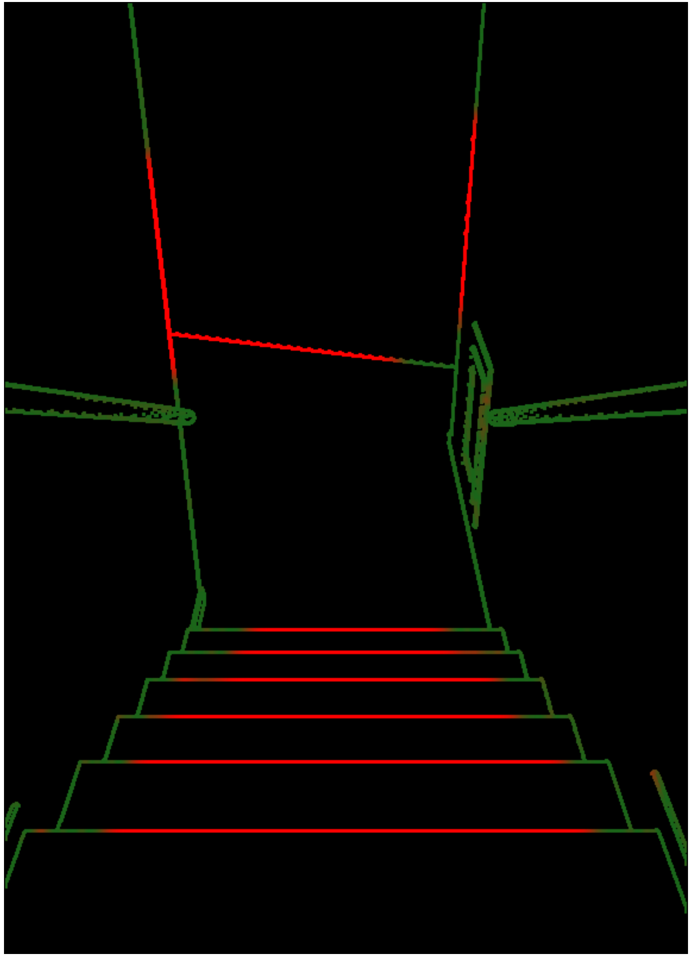




Low Vision: Mild

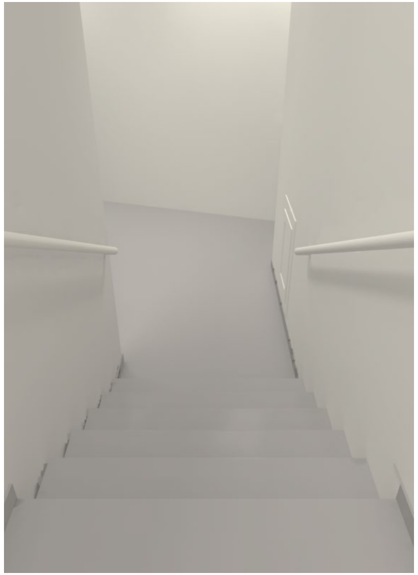
DeVAS
Steps Study

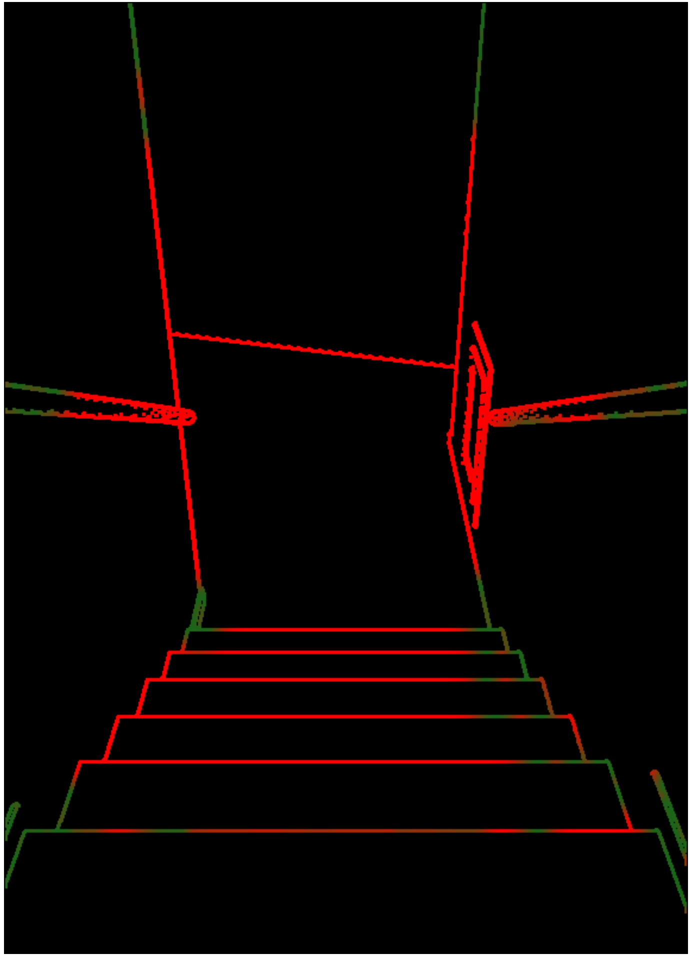




Low Vision: Moderate

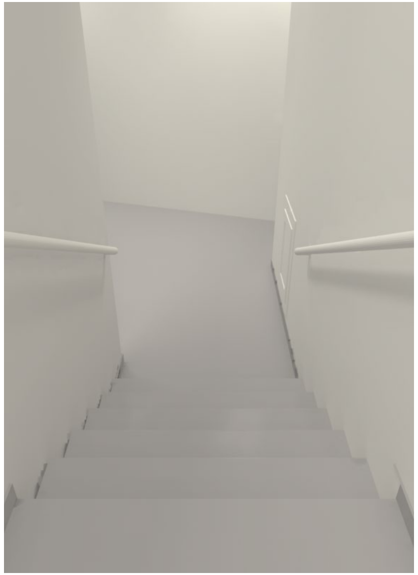
DeVAS
Steps Study

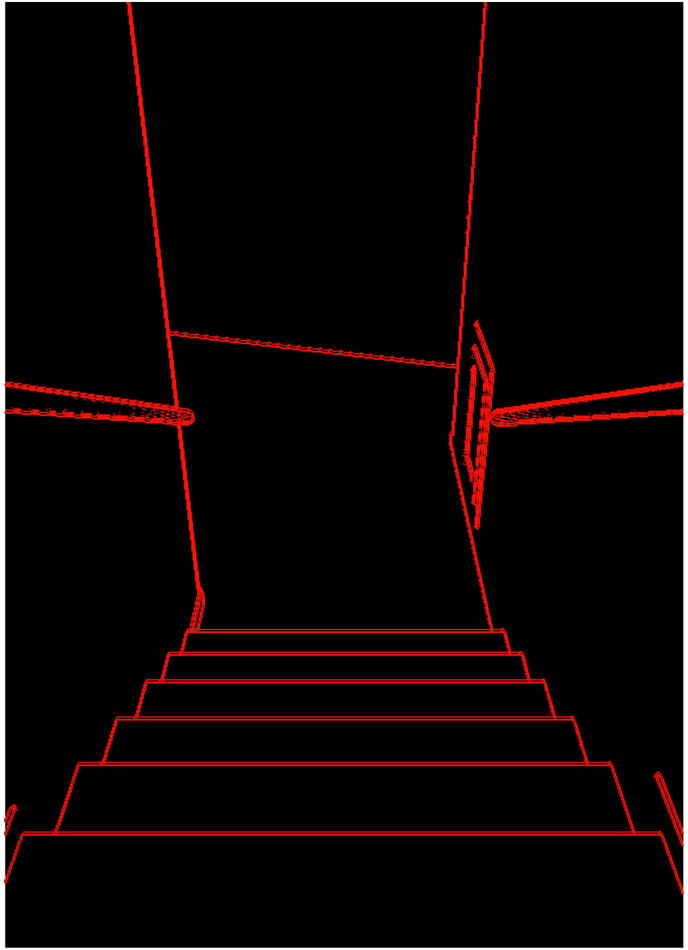




Low Vision: Severe

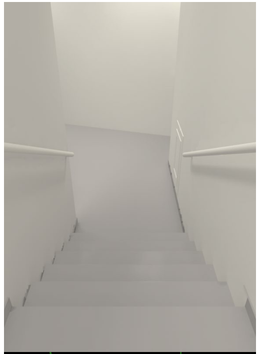
DeVAS
Steps Study

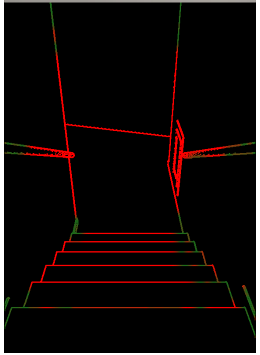


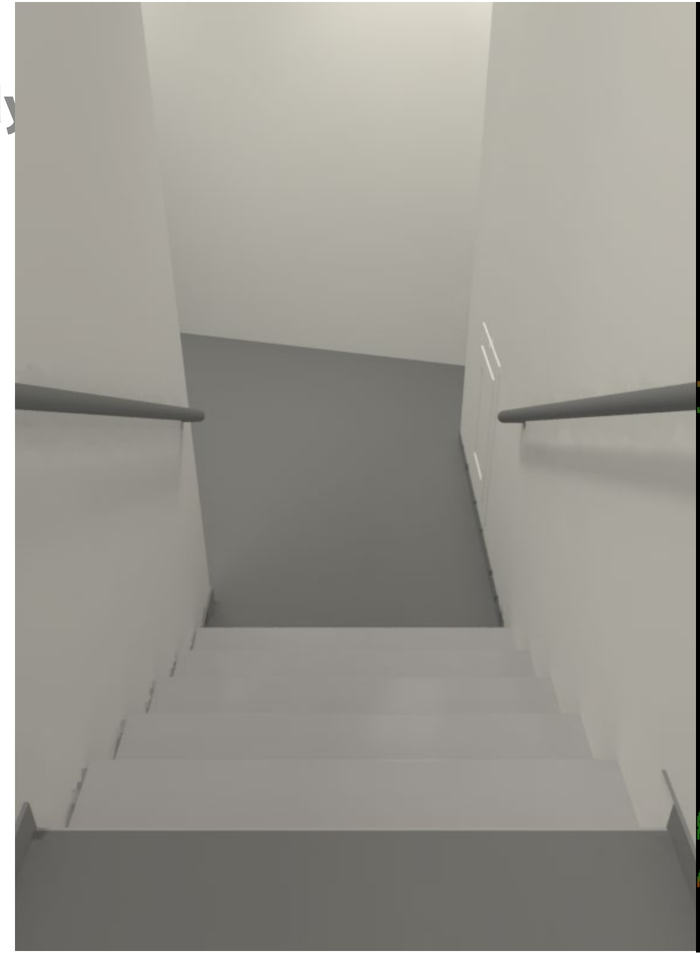


Low Vision: Profound

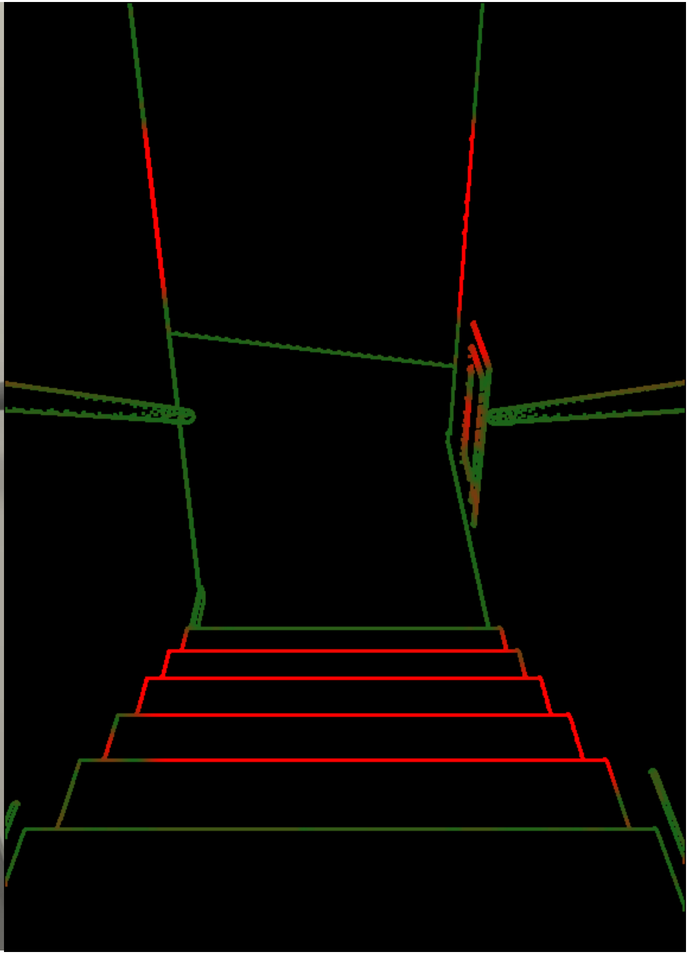
DeVAS
Steps Study





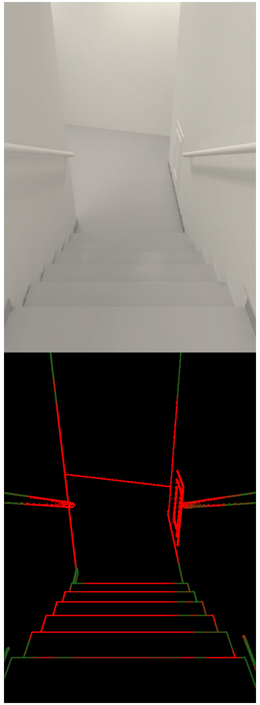


Change flooring

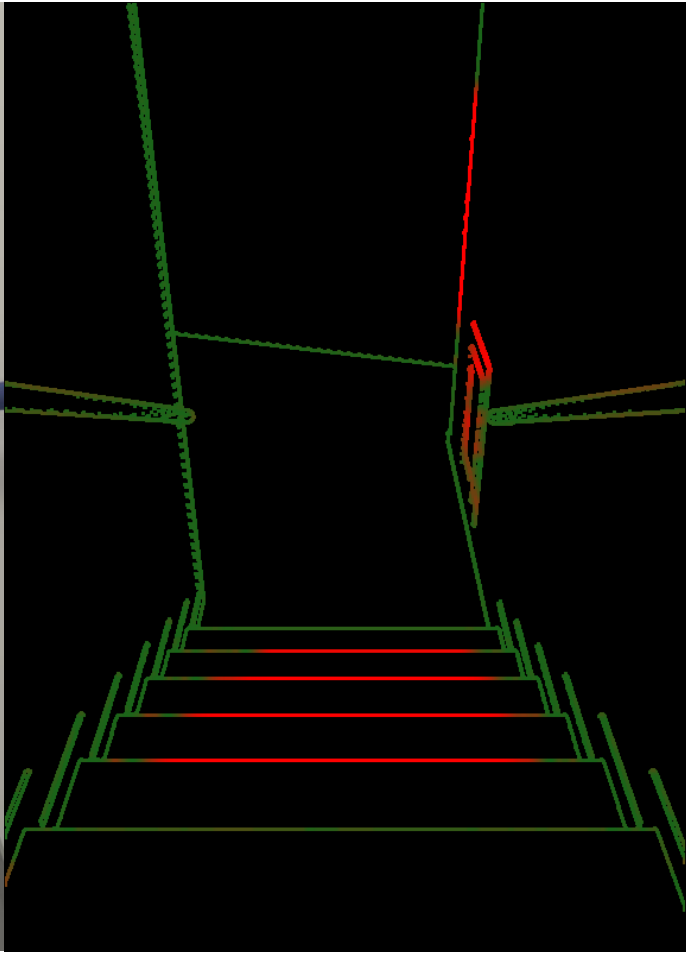


Low Vision: Severe

DeVAS
Steps Study

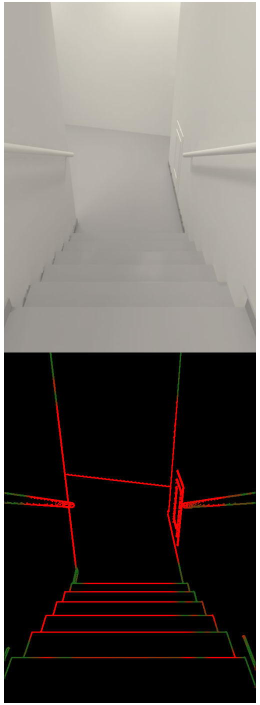


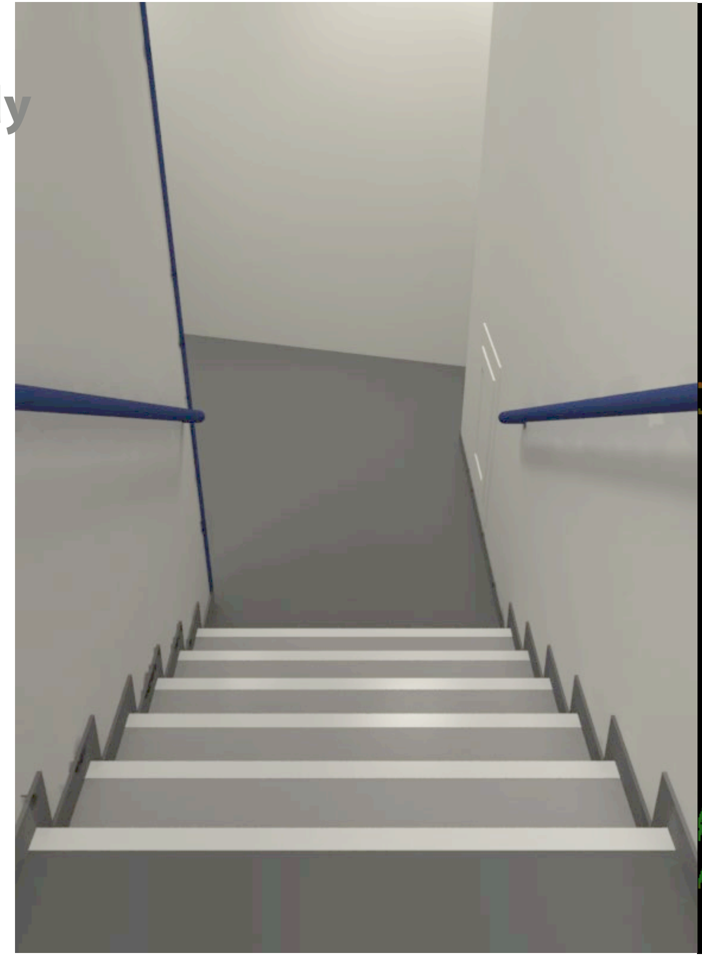
Change baseboards



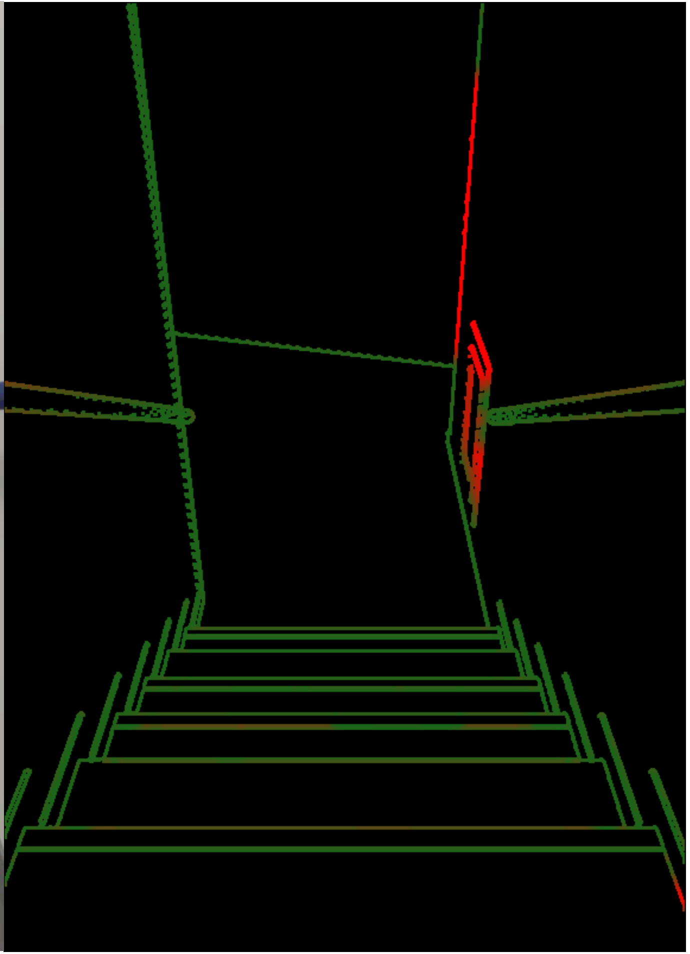
Low Vision: Severe

DeVAS
Steps Study



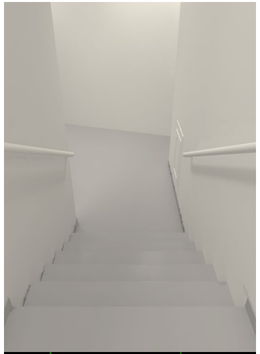


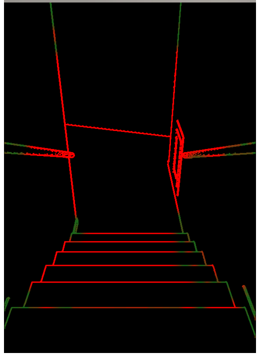
Add white stripes



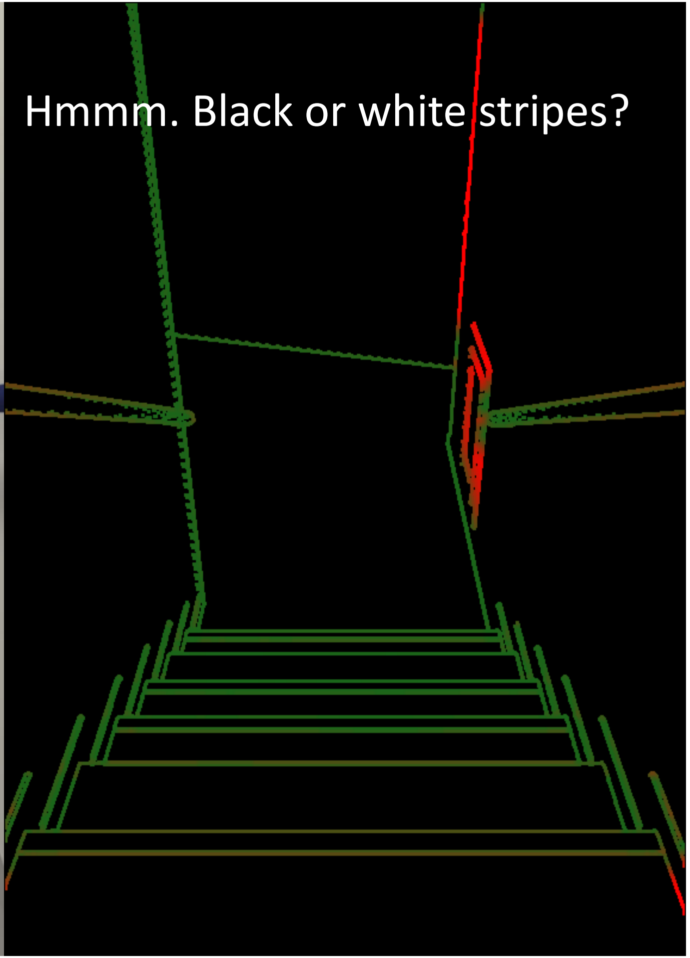
Low Vision: Severe

DeVAS
Steps Study



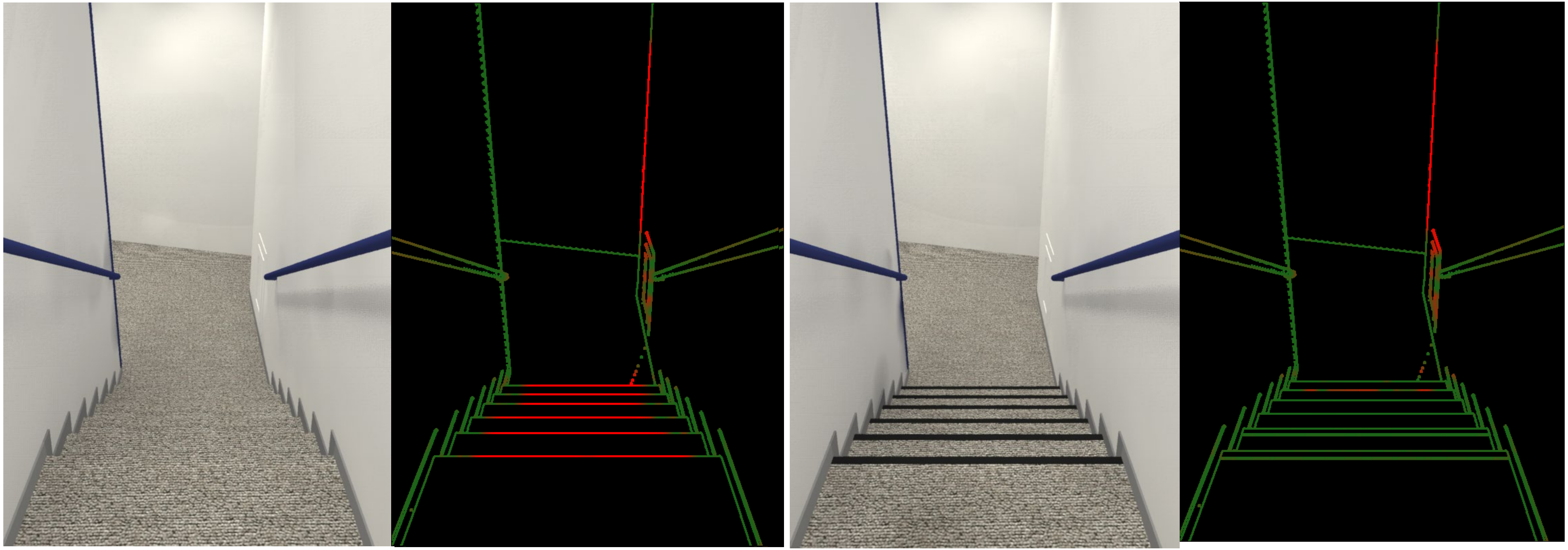


Black stripes +



Low Vision: Severe

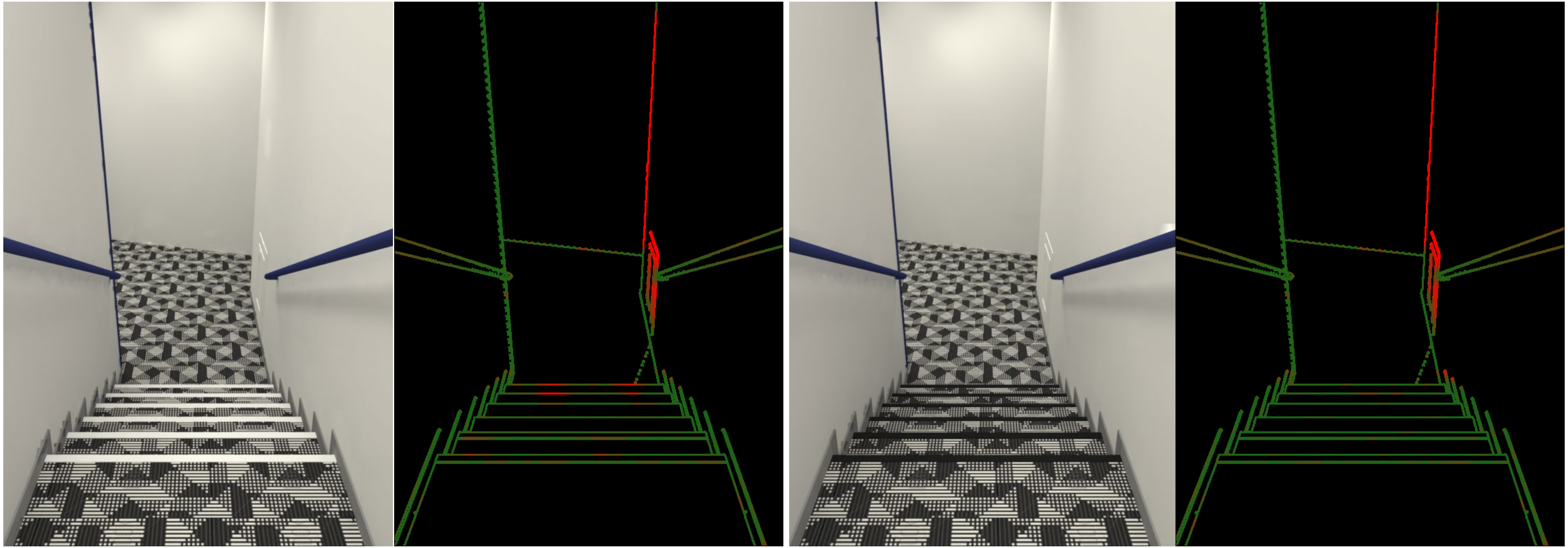
DeVAS
Steps Study



Low Vision: Severe

DeVAS
Steps Study

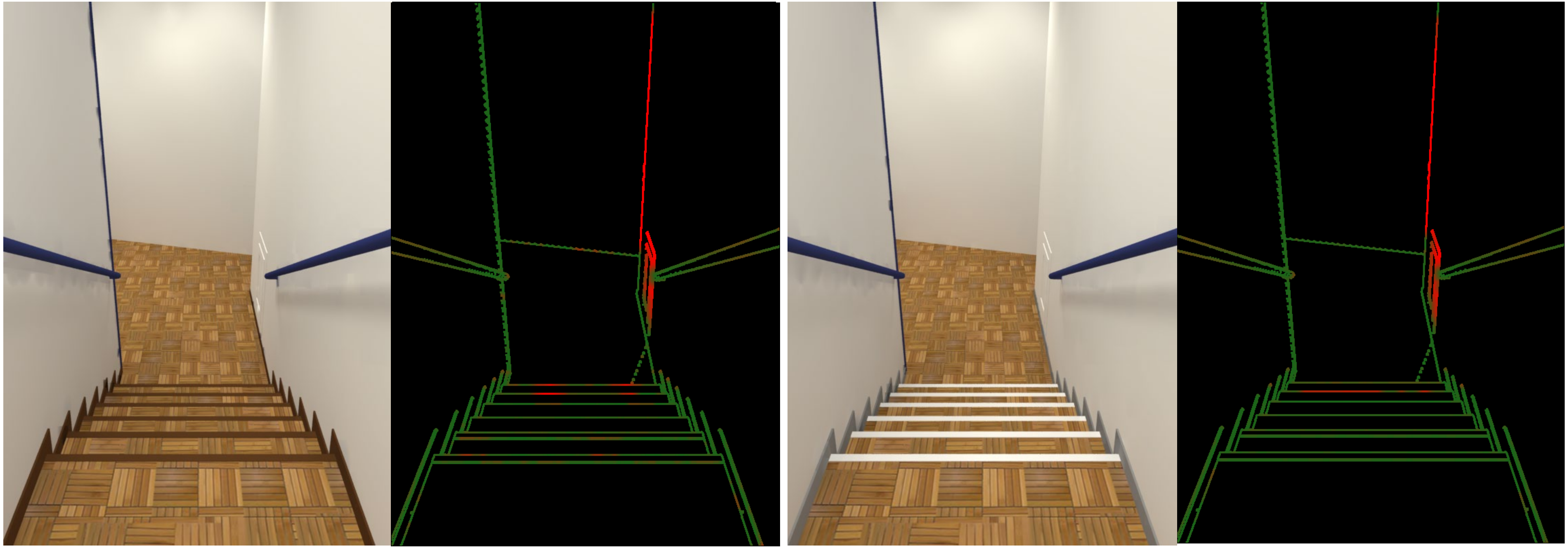
Hmmm. Which has greater visibility?



Low Vision: Severe

DeVAS
Steps Study

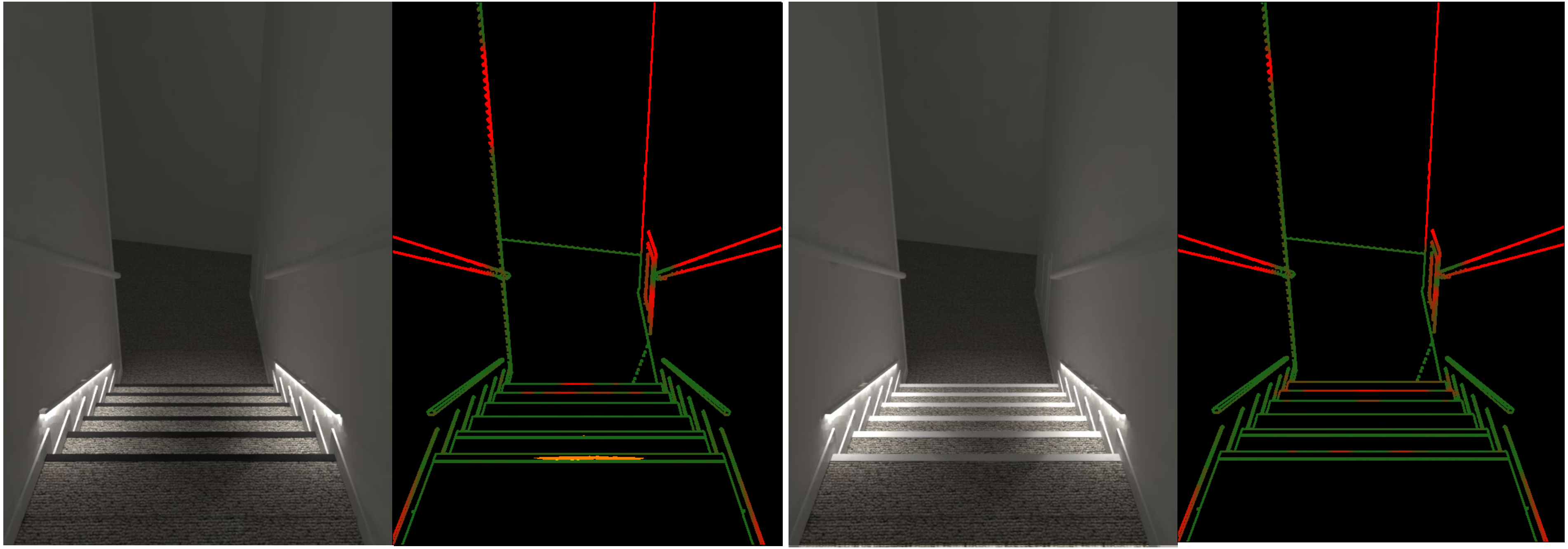
Hmmm. Which has greater visibility?



Low Vision: Severe

DeVAS
Steps Study

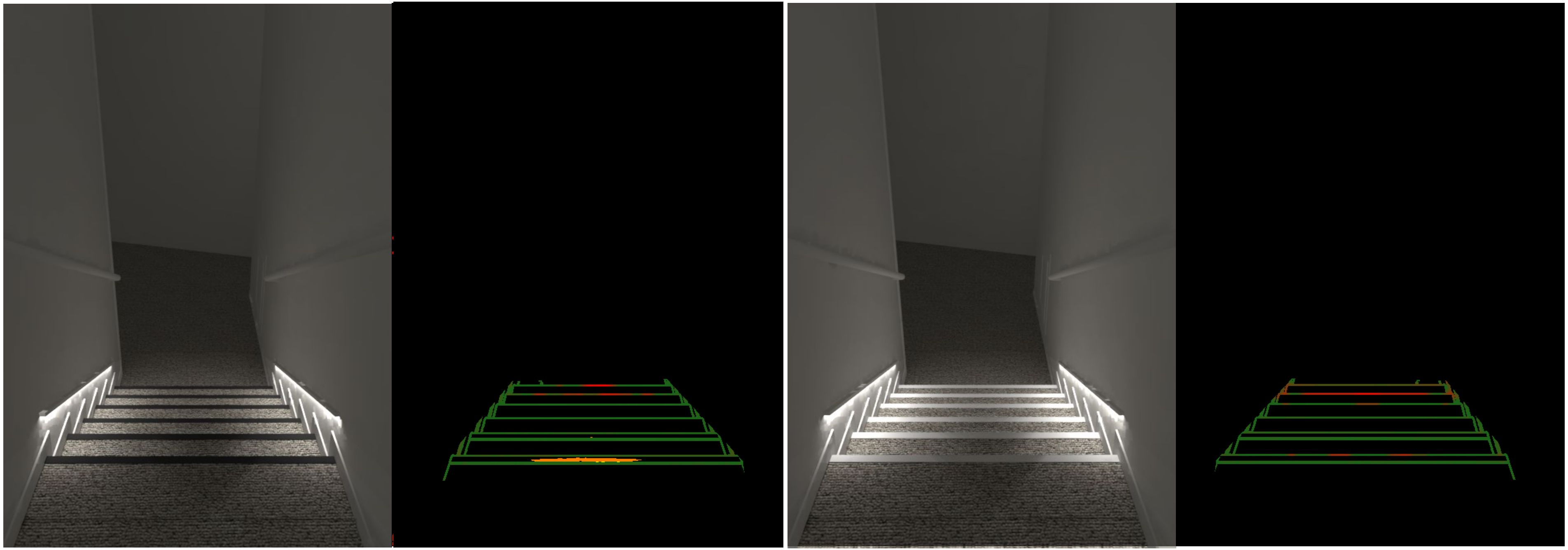
Hmmm. Which has greater visibility?



Low Vision: Severe

DeVAS
Steps Study

Hmmm. Which has greater visibility?

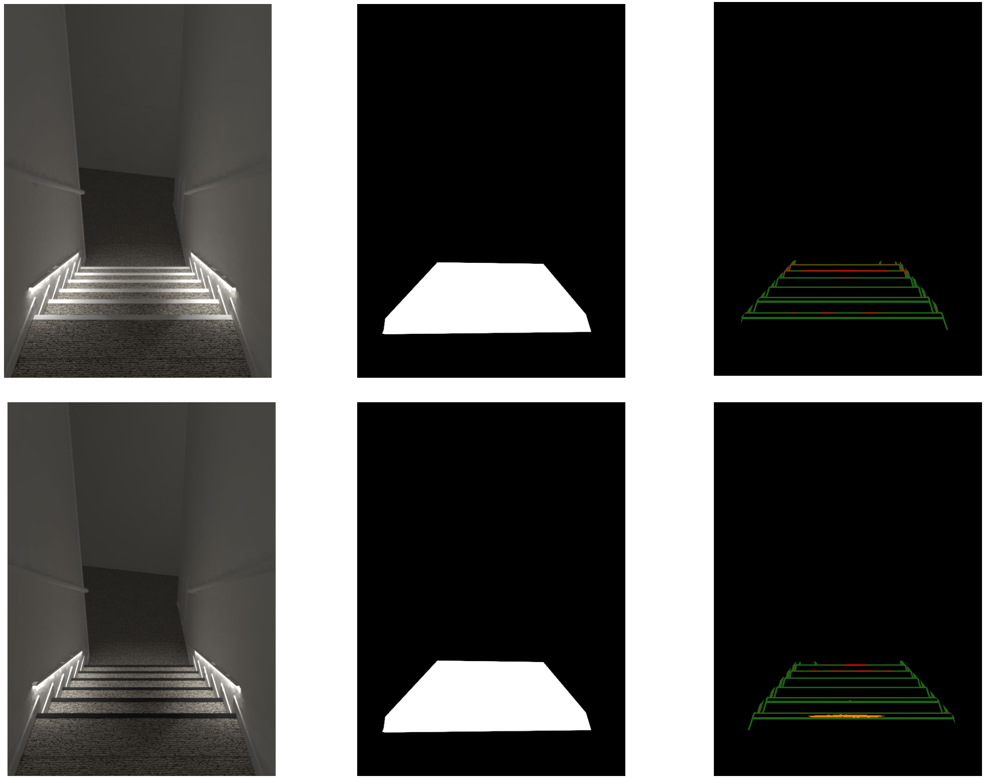


Low Vision: Severe

With user selected **Region Of Interest** (ROI)

DeVAS ROI

Hazard Visibility Score for comparison of same ROI. Not yet calibrated

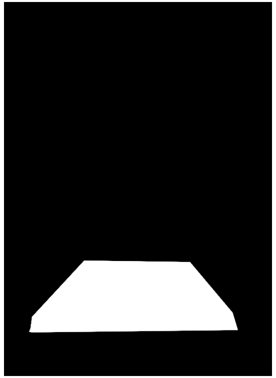


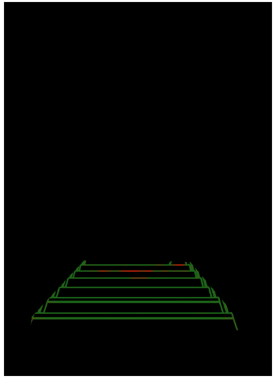
HVS: 0.900
Severe

HVS: 0.947
Severe

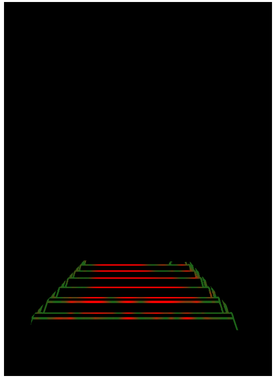
HVS 1.0 =   *highly visible*
HVS 0.0 =   *invisible*

DeVAS
ROI



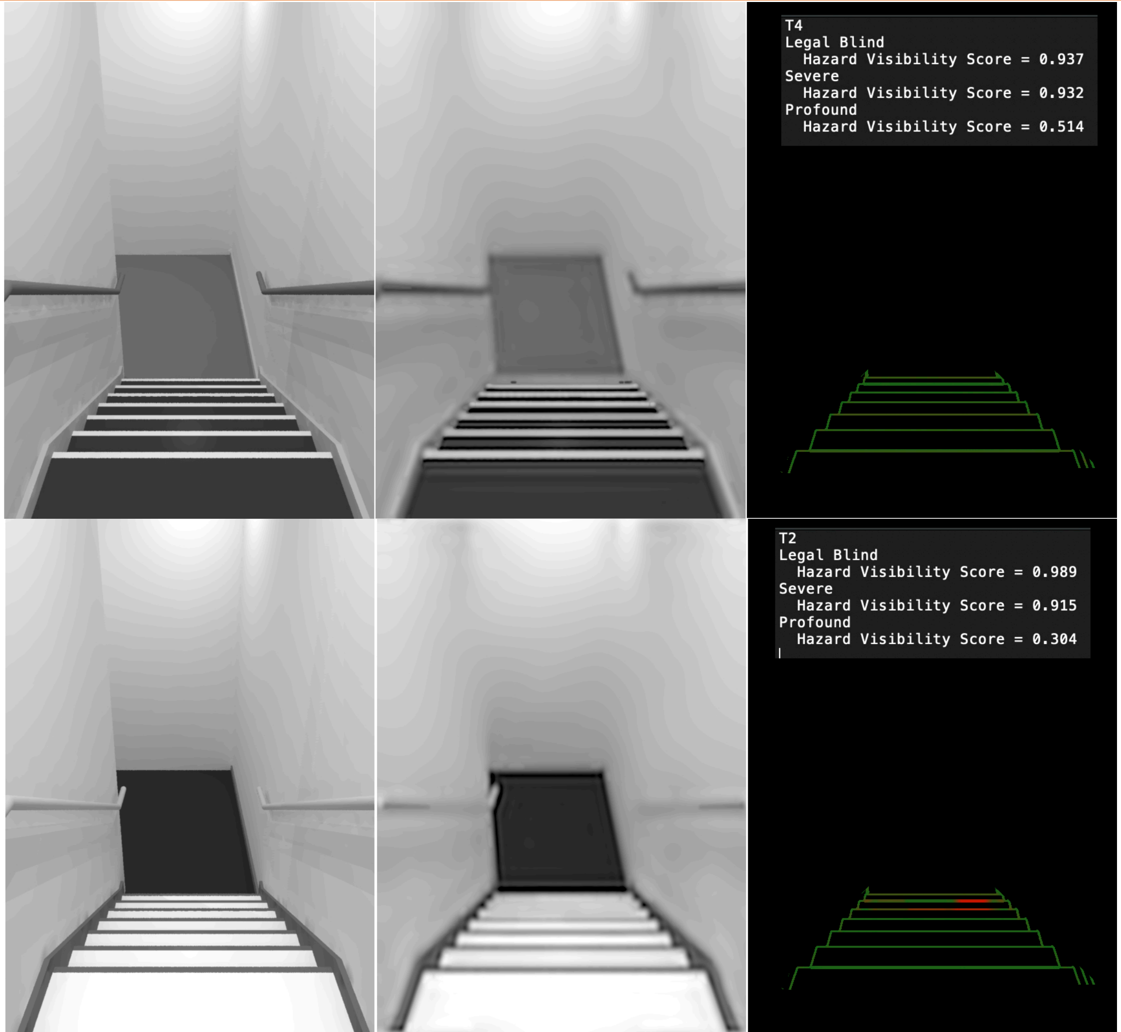


HVS: 0.962
Severe



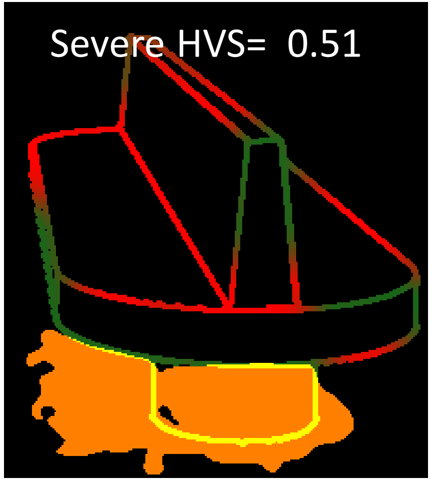
HVS: 0.597
Profound

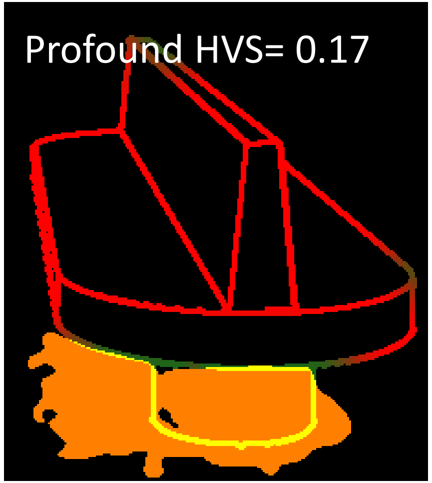
DeVAS Steps Study



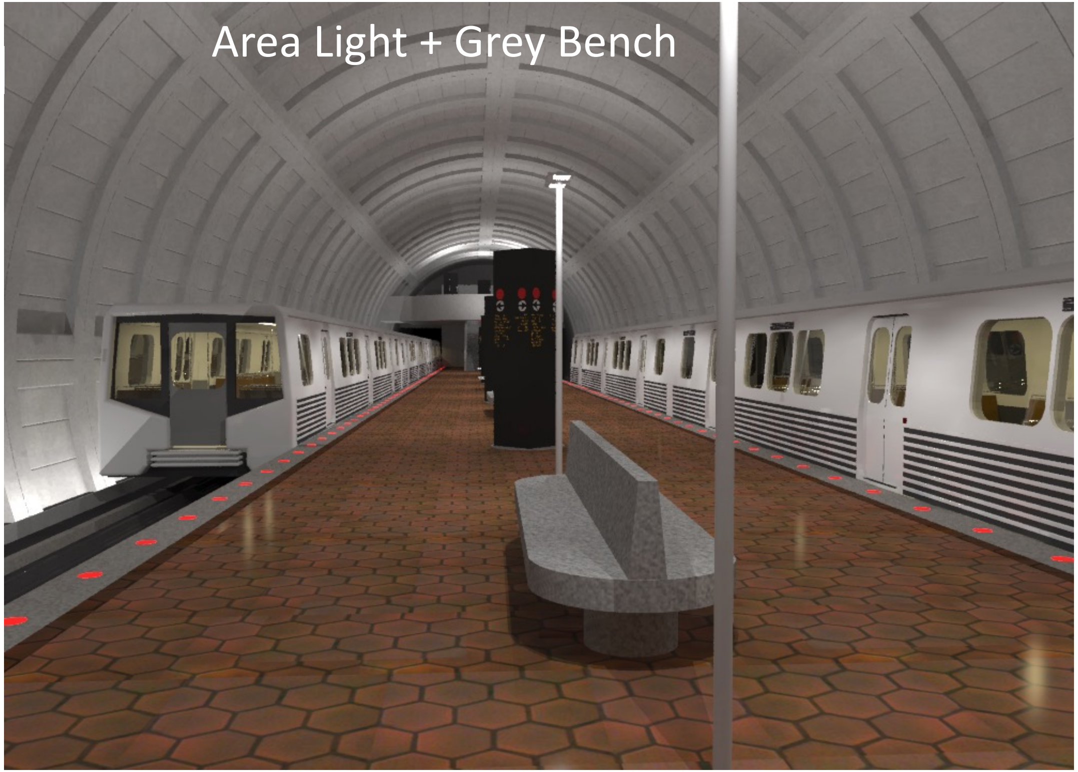
DeVAS
HVS

Mild	HVS= 0.84
Moderate	HVS= 0.74
LB	HVS= 0.67
Severe	HVS= 0.51
Profound	HVS= 0.17

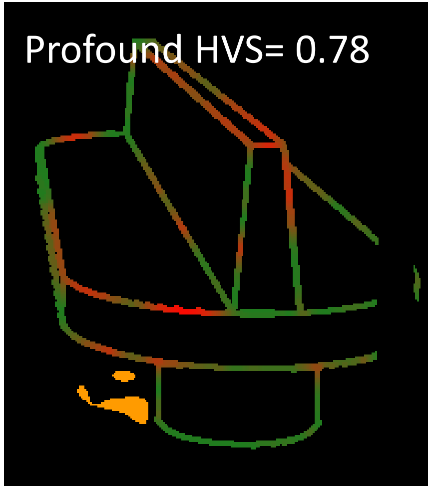




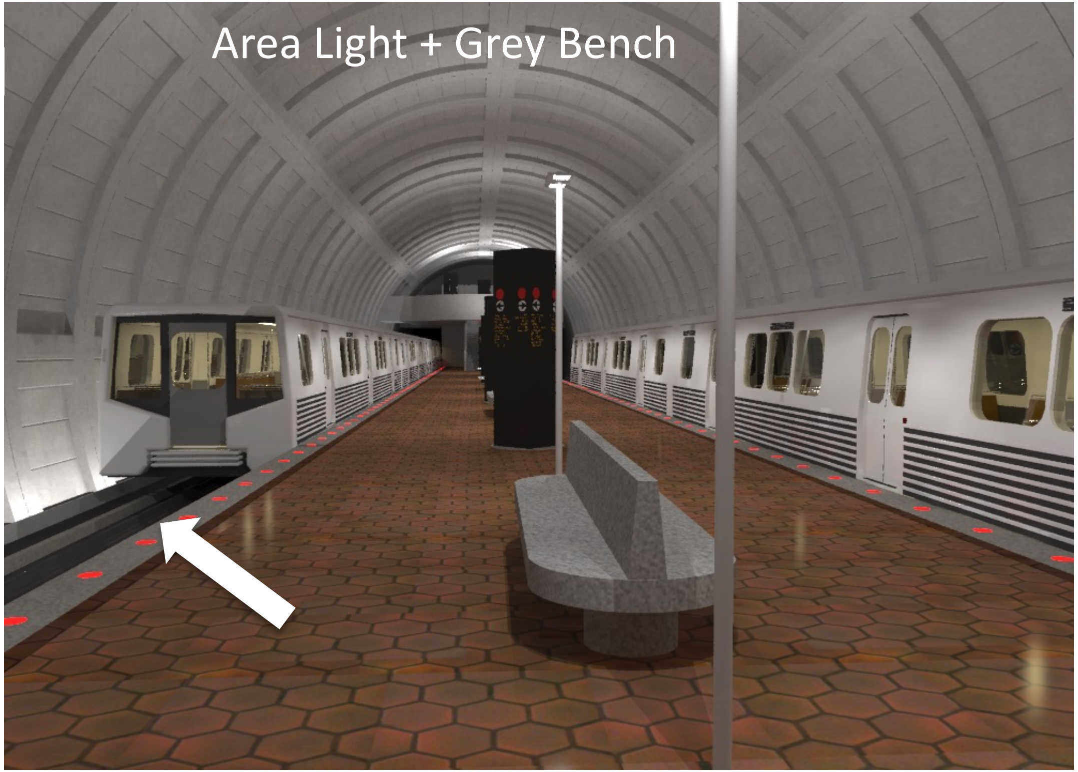
DeVAS HVS

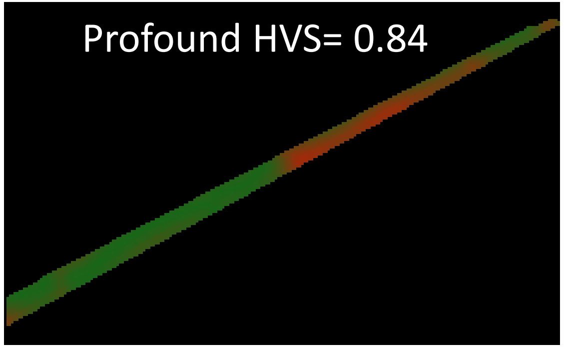


Mild	HVS = 0.99
Moderate	HVS = 0.98
LB	HVS = 0.95
Severe	HVS = 0.92
Profound	HVS = 0.78



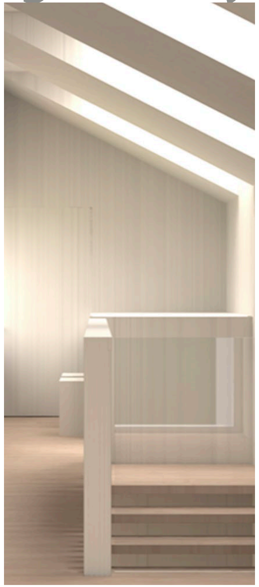
DeVAS HVS

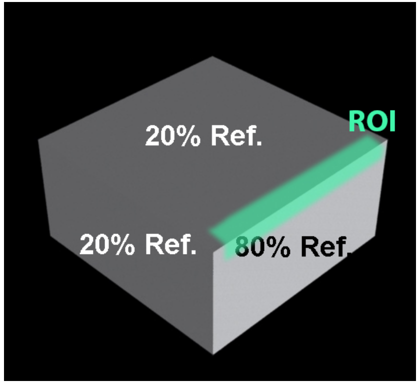




Mild	HVS = 0.97
Moderate	HVS = 0.98
LB	HVS = 0.98
Severe	HVS = 0.98
Profound	HVS = 0.84

DeVAS
Daylight Study

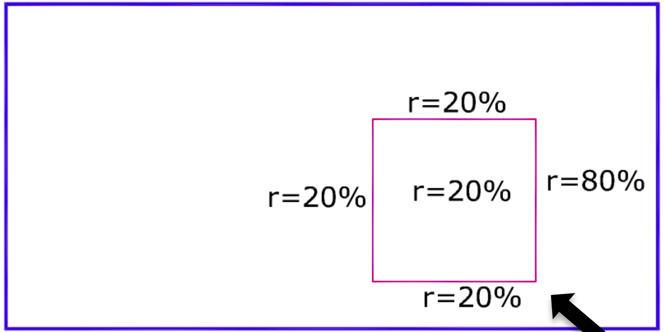




Design by luminance

48" x 96" skylight at 8' above floor

WEST

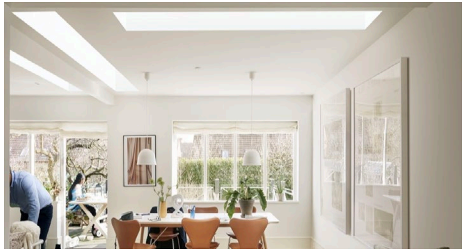


EAST

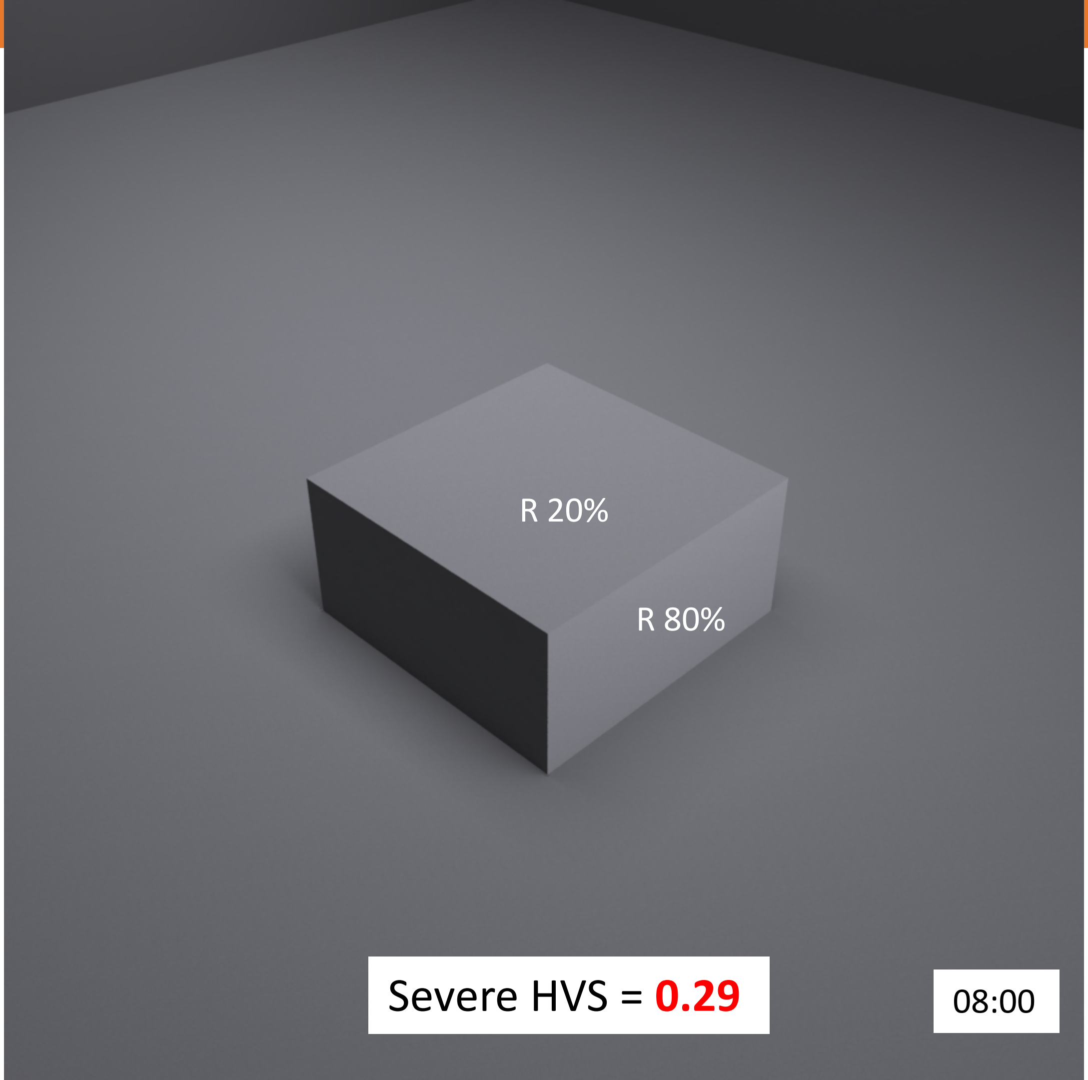
r=20%

24" x 24" x 12"(H) box

VIEW



DeVAS
Daylight Study

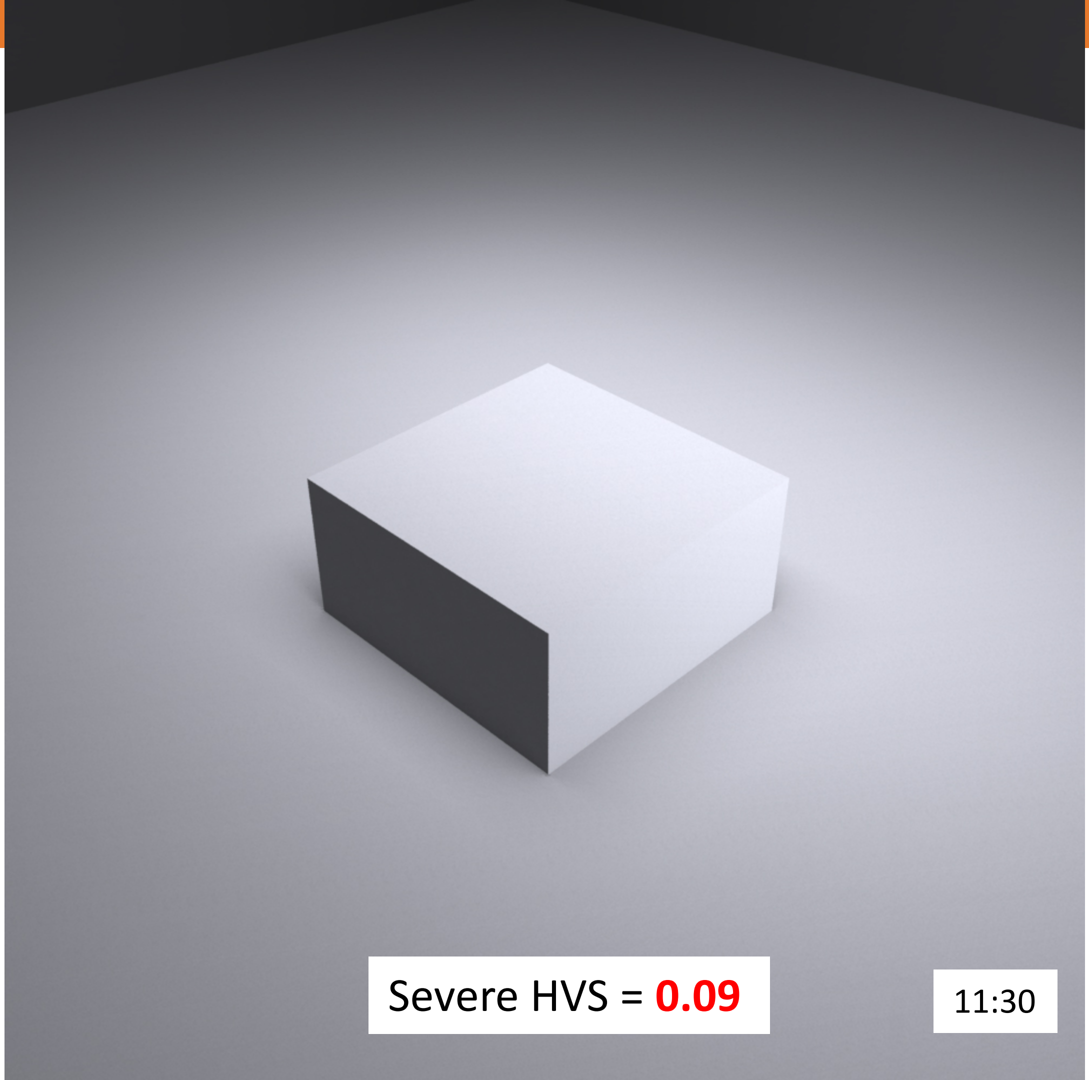


DeVAS
Daylight Study

DeVAS
Daylight Study

DeVAS
Daylight Study

DeVAS
Daylight Study



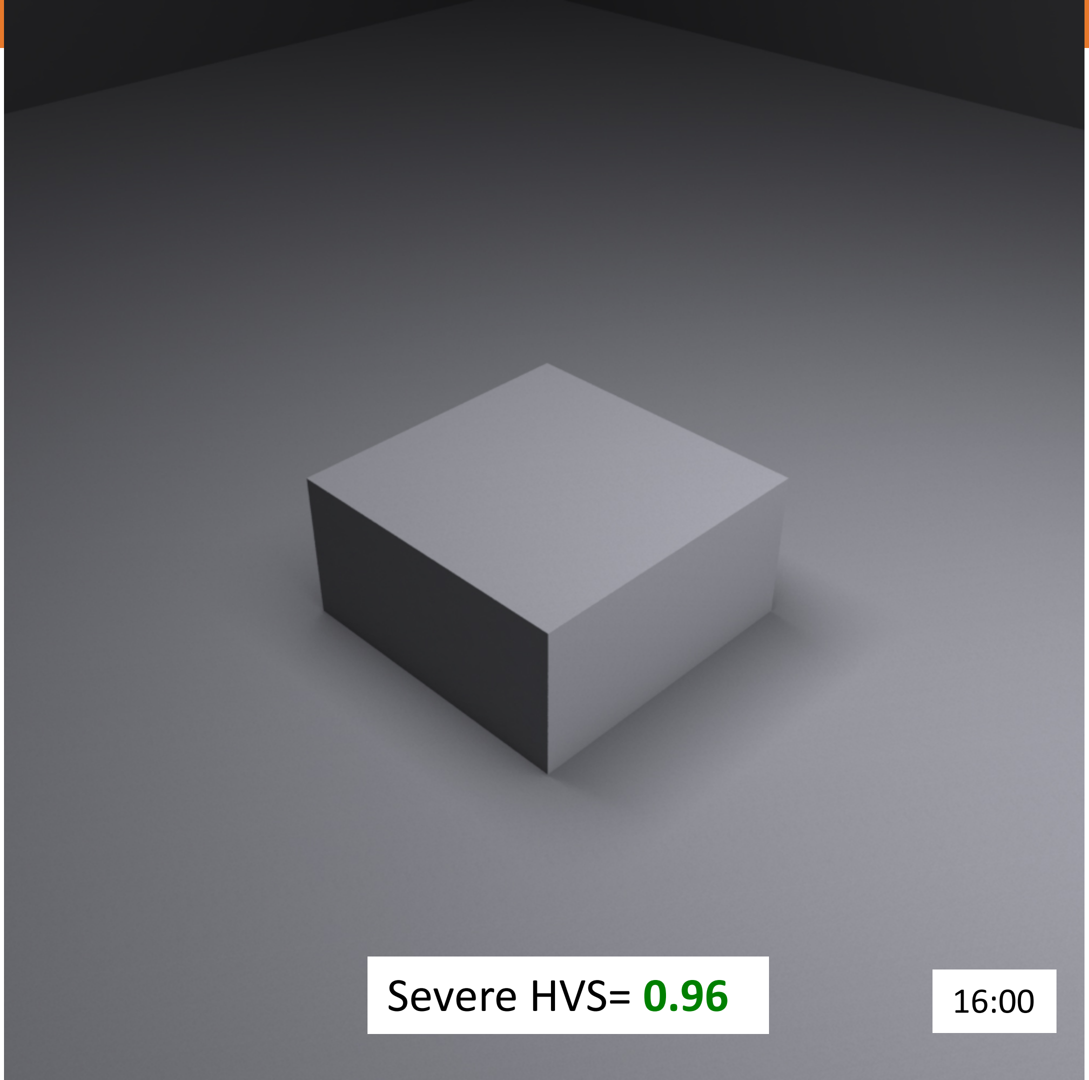
DeVAS
Daylight Study

DeVAS
Daylight Study

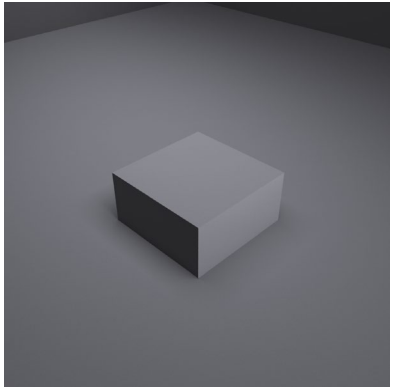
DeVAS
Daylight Study

DeVAS
Daylight Study

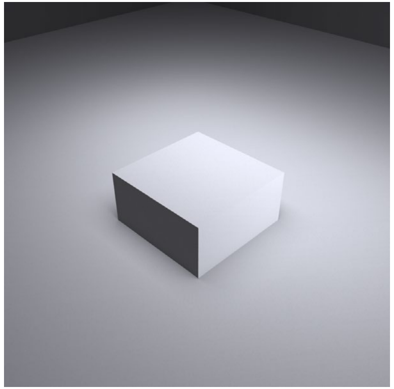
DeVAS
Daylight Study



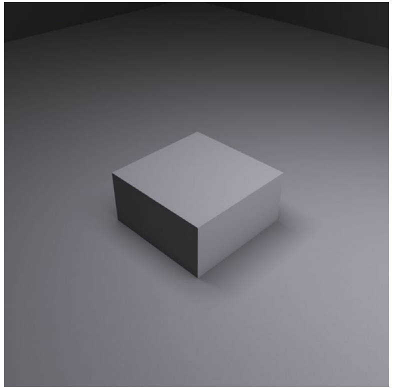
DeVAS
Daylight Study



Severe HVS = 0.29 8:00



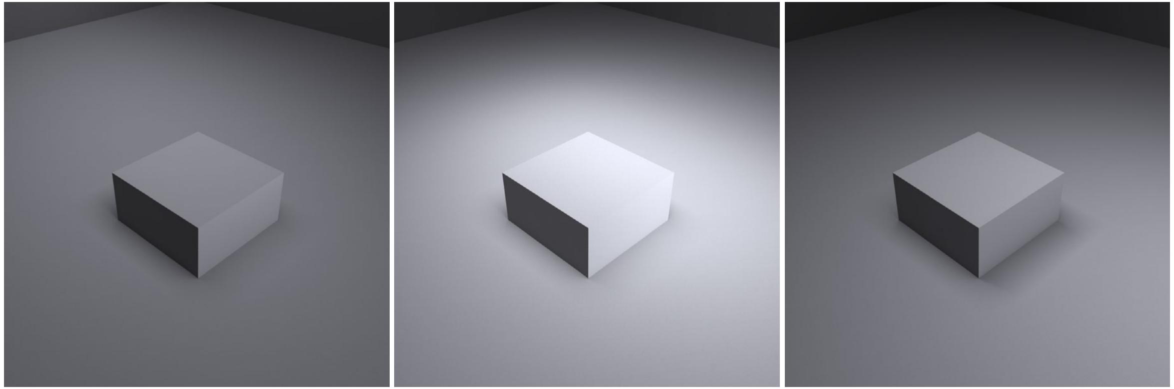
Severe HVS = 0.09 11:30



Severe HVS = 0.96 16:00

Possible annual atrium/exterior daylight HV studies?

DeVAS
Daylight Study



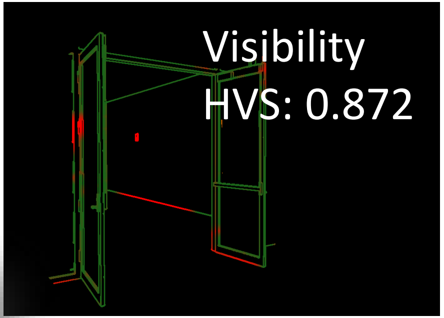
Severe HVS = 0.29 8:00 Severe HVS = 0.09 11:30 Severe HVS = 0.96 16:00

Possible annual atrium/exterior daylight HV studies?

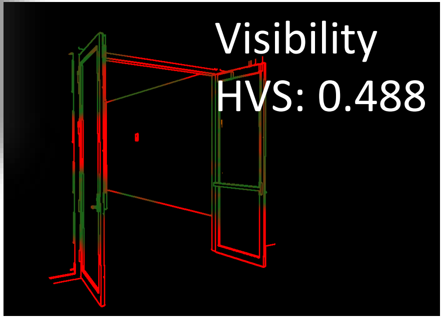
Determine dangerous hazard times/dates and address

DeVAS Toolset

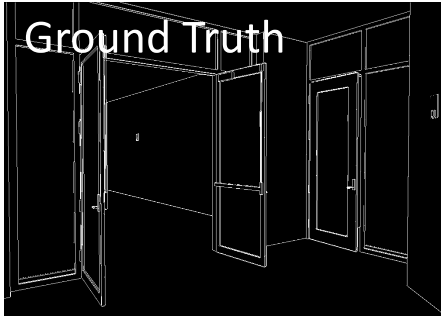
Mild
Moderate
LB
Severe
Profound

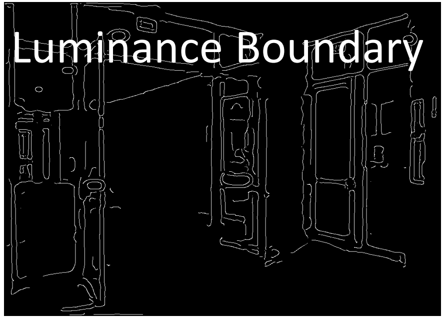


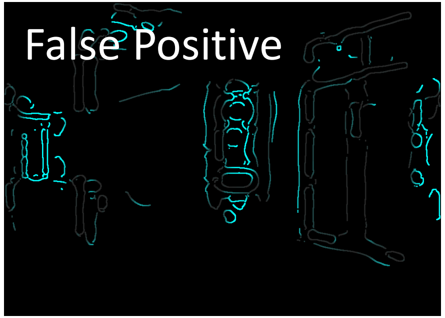
Severe 20/285 + CSF



Profound 20/710 + CSF

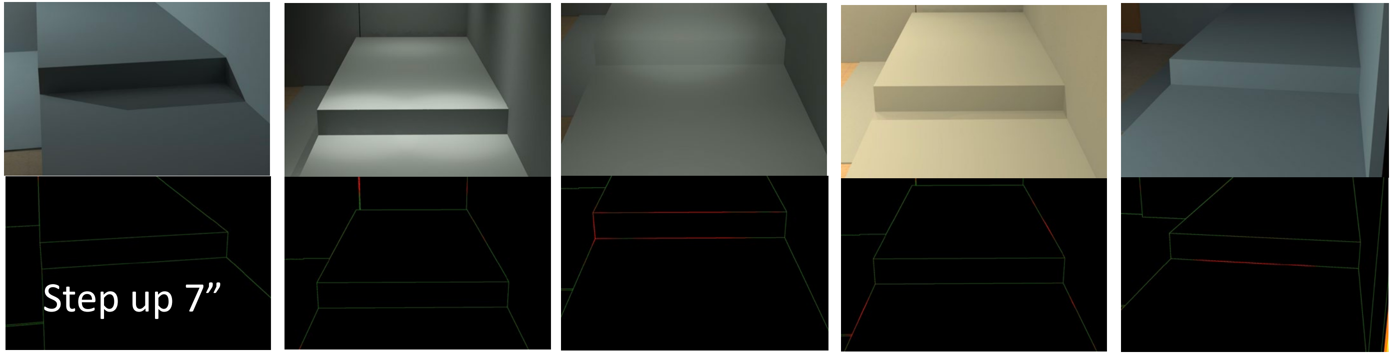


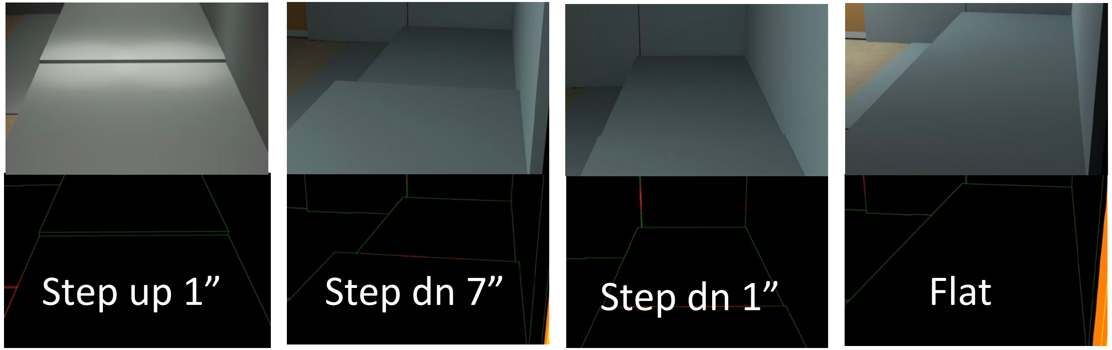




DeVAS Validation Study Results: Simulated Low Vision

5 Views x 5 Platform Variations x 5 Lighting Conditions = 125 images each with HVS for SEV & PRO



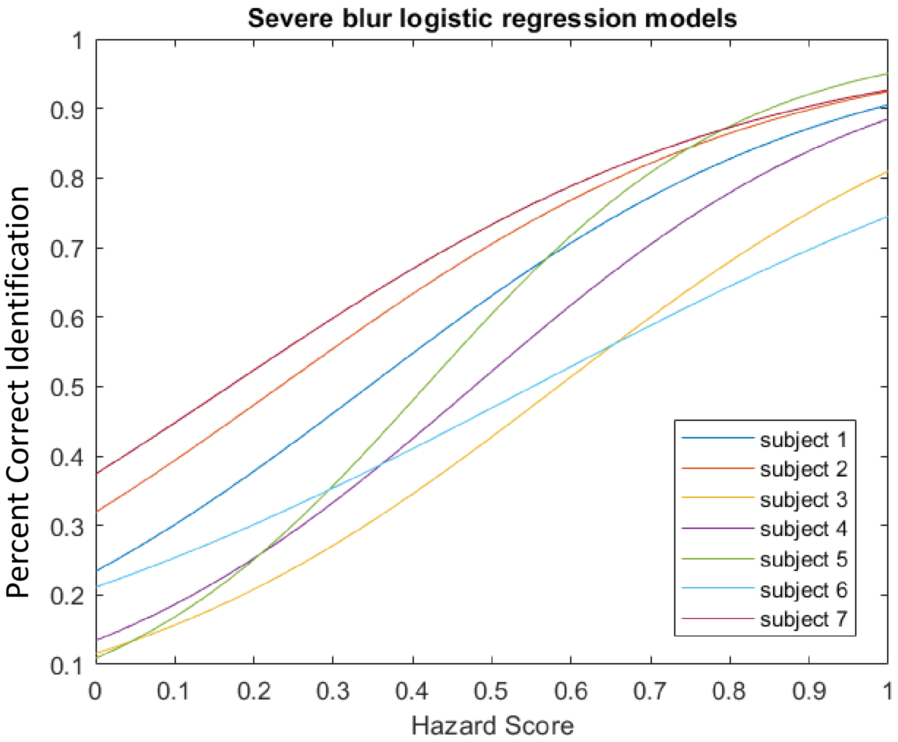


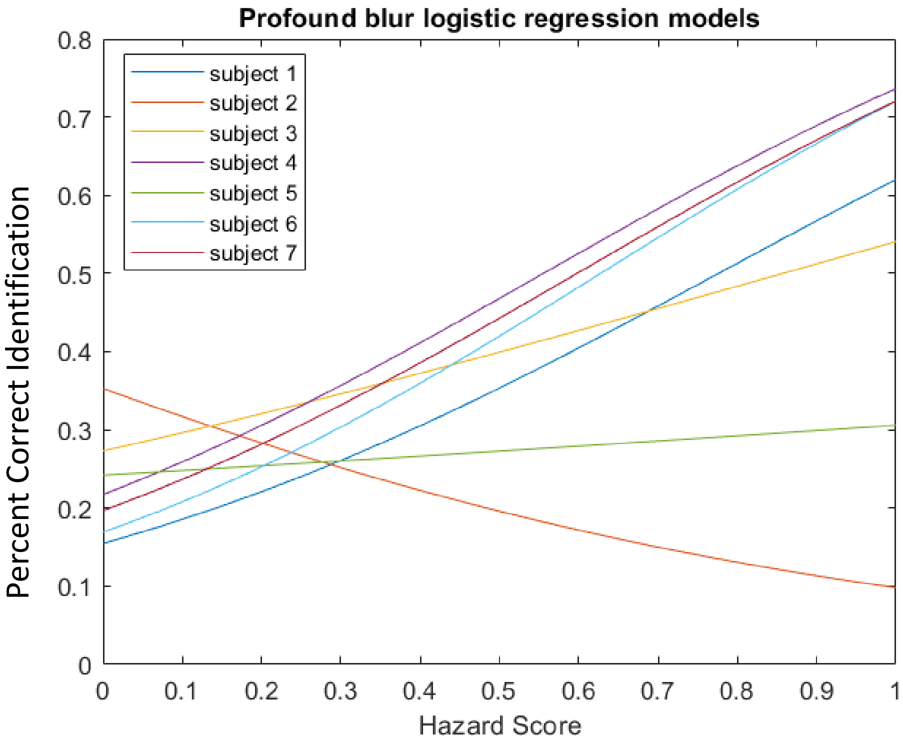
Randomly viewed twice
at SEV and PRO Low Vision

250 images x 14 subjects = 3500 samples

DeVAS Validation Study Results: Simulated Low Vision

Hazard Visibility Score (HVS) predicts **Human Performance**!
- As HVS increases, probability of identifying the step correctly increases

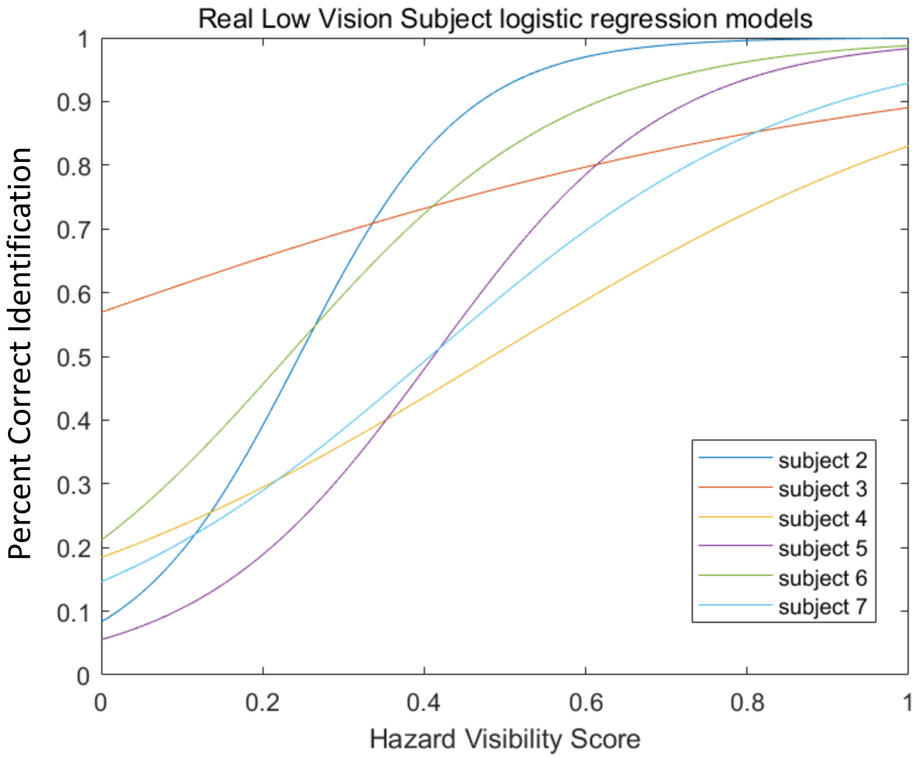




DeVAS Validation Study Results: Low Vision Individuals (from ongoing study)

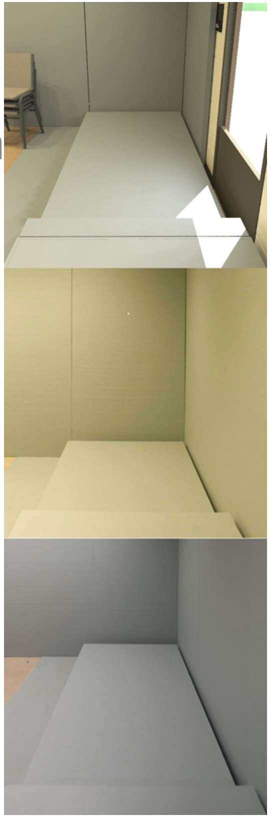
Hazard Visibility Score (HVS) predicts **Human Performance**!

- As HVS increases, probability of identifying the step correctly increases



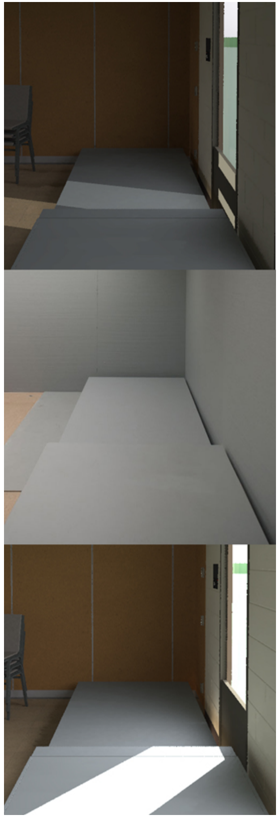
Hazard Visibility: View Dependen

5’



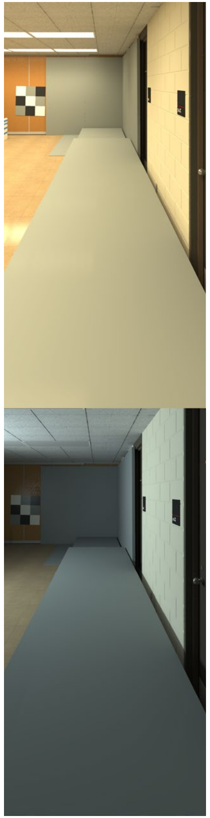
Crucial

10’



Important

20’



Desirable

DeVAS Limitations

View Dependent

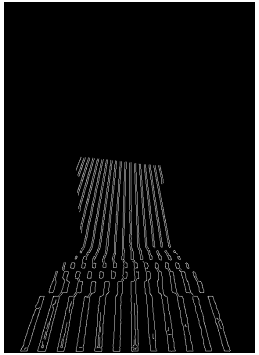
Requires lighting and material specifications

Very high luminance areas can mask nearby lower luminance details

Strident high contrast material patterns can result in incorrect visibility analysis

Visibility Recommended Practice to evaluate: Compliant/not Compliant

Simulation



Luminance Boundaries

Photographs

DeVAS Limitations

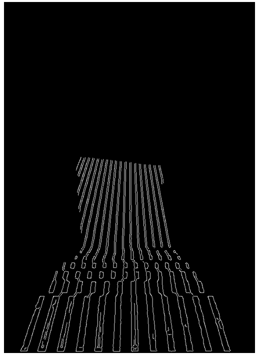
View Dependent

Requires lighting and material specifications

Very high luminance areas can mask nearby lower luminance details

Strident high contrast material patterns can result in incorrect visibility analysis

Visibility Recommended Practice to evaluate: Compliant/not Compliant



Future Work

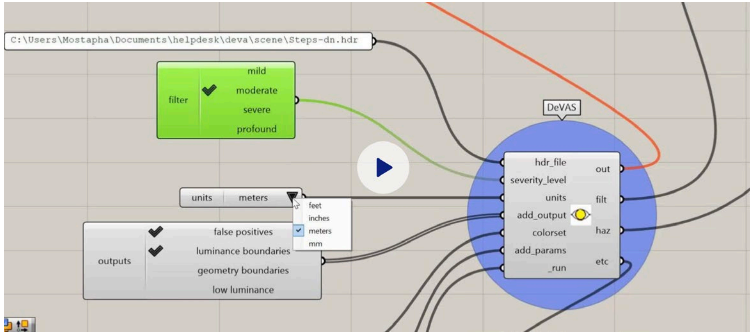
Extensive testing over many different physical spaces

Additional testing and calibration with low vision subjects

User interface work to make the system user friendly
(by developers)

DeVAS Future

DeVAS Tools are open source, fully functional prototypes compiled for Windows and OSx. DeVAS Visibility is being incorporated into LADYBUG, a RHINO/GRASSHOPER plugin. We welcome other developers.



rtpict: a gift from Greg that generates and associates all files necessary for DeVAS-visibility

RTPICT(1) RTPICT(1)

NAME

rtpict - generate a RADIANCE picture or layerd image using rtrace

SYNOPSIS

rtpict -n nproc [-o[vrxlLRXnNsmM] out_dir][-d ref_depth/unit] [rpict options] [@file] octree

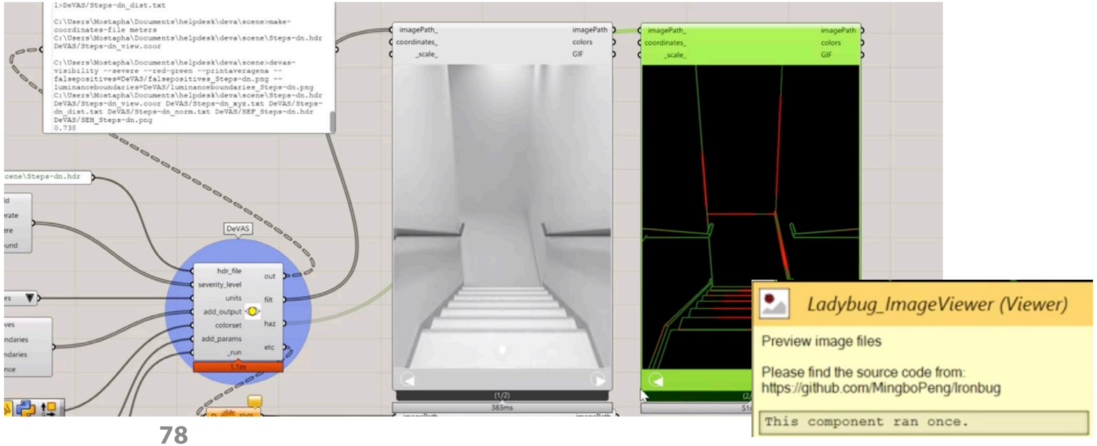
DESCRIPTION

Rtpict is a script that generates a picture from the RADIANCE scene given in *octree* and sends it to the standard output, or to a file specified with the *–o* option. Most options and defaults are the same as *rpict(1)*, although a few switches are silently ignored. Options incompatible with multi-processing can generate an error.

The *rtrace(1)* tool is called with *vwrays(1)* to perform the actual work. This enables the *–n* option for multiprocessing on platforms that support it. If the *–n* option is not specified or is set to 1, then *rpict* is called directly. There is no benefit in setting the number of processes to anything greater than the number of virtual cores available on your machine. Also, it is very important to set the *–af* option if an irradiance cache is being generated; otherwise, your speed-up will be far from linear.

If the *–o* option has additional characters corresponding to output types from *rtrace*, it must be followed by the name of a directory that either exists or will be created to contain image layers, one per output type. The supported types are listed below, and do not include types that are useless or have no convenient representation. The table below shows the correspondence between output type and file name in the specified directory:

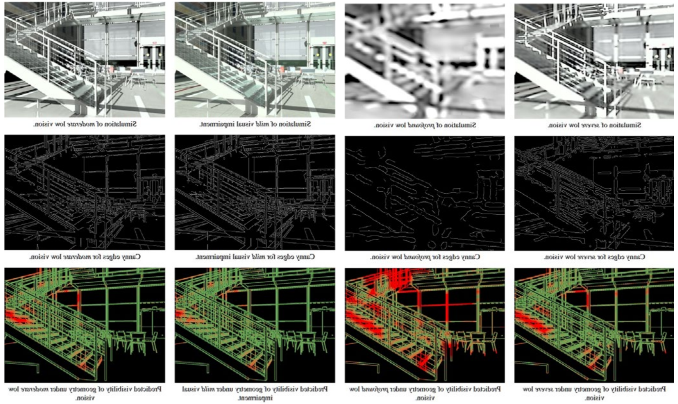
v	radiance.hdr
r	mirrored.hdr
x	unmirrored.hdr
l	effective.dpt
L	firstsurface.dpt
R	mirrored.dpt
X	unmirrored.dpt
n	perturbed.nrm
N	unperturbed.nrm
s	surface.idx
m	modifier.idx
M	material.idx

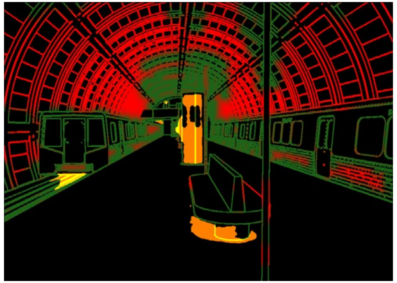


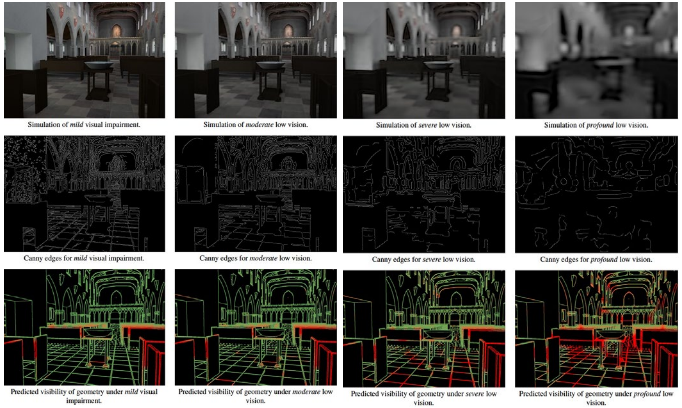
DeVAS Future

DeVAS tools enable the designer to analyze and improve visibility of hazards, potentially within the design palette of the project

Standards could potentially be structured for luminance studies, such as DeVAS, where compliance is sought to a visibility metric standard







DeVAS Summary

The DeVAS-visibility tool provides a proof-of-concept for a design process that uses (1) viewpoint-specific luminance-based analysis and (2) simulations of low vision, to aid in the creation of architectural spaces that are accessible to those with vision impairment who make use of vision for mobility.

Currently, it can be used as a tool for enhancing visual accessibility as a part of universal design. With additional data collection from actual low vision individuals on hazard visibility in realistic settings, and with specification of critical viewpoints for hazard detection, the DeVAS system can provide a starting point for **luminance-based design standards**.

Designing Visually Accessible Spaces (DeVAS):
A Tool to Predict Visibility of Potential Hazards During the Design Phase

Recent focus group presentations/discussions include:

Access Board, ADA, Washington, D./C.

"..the direction which our work has opened up will very likely change the focus of future more robust visual accessibility code"

ARUP, Lighting Design Group, World Headquarters, London, G.B

"Design for inclusiveness is important now" "Absolutely add this to our workflow. Safety is a concern, and the tool helps with that"

VELUX, Knowledge Center, Horsholm, Denmark

"The tool is exciting " "Consider an image format which contains geometry to upload for cloud processing"

Moody Nolan, Architects, Columbus, Ohio

" Fantastic tool!" "We hope it gets developed into a tool we can use"
"Consider adding points to LEED, WELL Building, Fitwel certifications
for buildings that use the tool and comply with the guidelines"

DIVA, Environmental Analysis for Buildings

"we would implement this tool in our software suite tomorrow, if there were recommended practices for compliance"

DeVAS
Questions and Comments?

Principal Research Team:
Dr. Gordon Legge, Psychology, Low Vision Lab, University of Minnesota
Dr. Dan Kersten, Psychology, Computational Vision, University of Minnesota
Dr. Bill Thompson, Computer Science, University of Utah,
Dr. Sarah Creem-Regehr, Psychology, Cognition and Neural Science, University of Utah
Rob Shakespeare, Lighting Designer, Indiana University

Questions and Comments?

Thank you!

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