Contours and Contrast

Kaleigh Smith

Contours and Contrast

Not news: actual contrast creates a contour.

News: contour creates apparent contrast.

-- Floyd Ratliff (1919-1999), Contour and Contrast, 1970

Contours and Contrast

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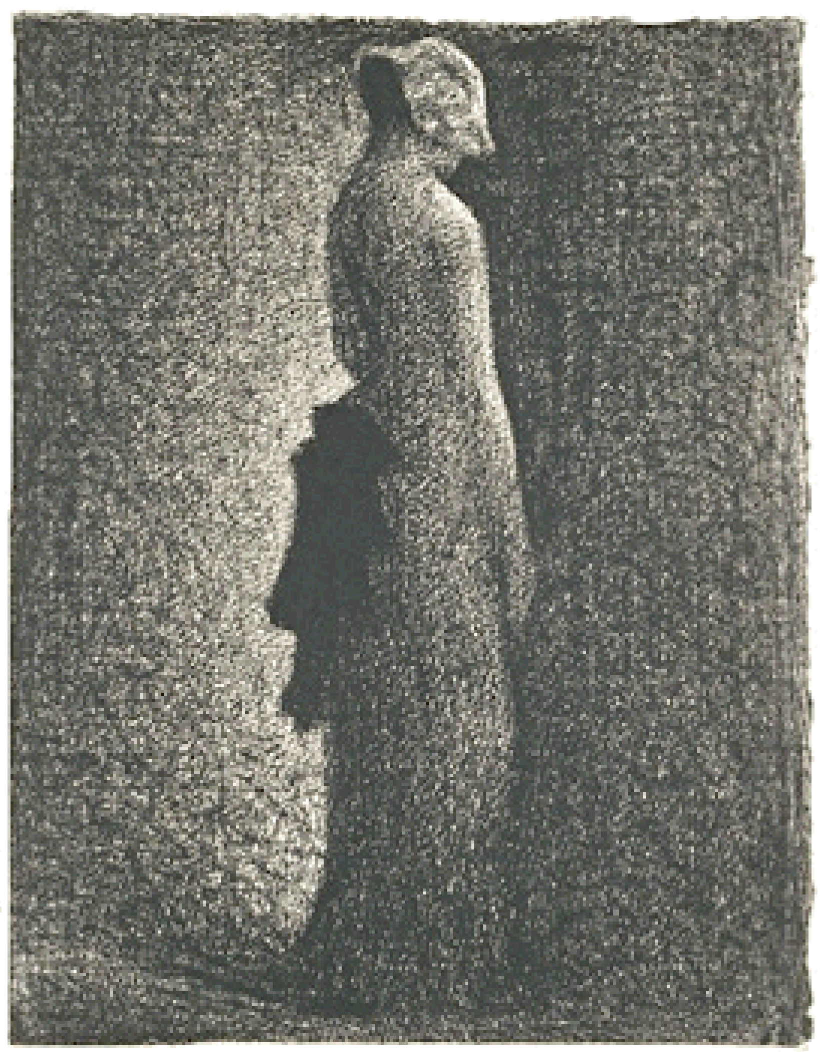
Contrast Depiction

If we could but paint with the hand what we see with the eye.
-- Honore de Balzac (1799-1850)

Contrast Depiction The visual communication of all the important contrasts making up a real or synthetic scene. The challenge is to create an image that overcomes the constraints imposed by the depiction medium.



Le Noeud Noir, Georges Seurat 1882

Contours removed, contrast reduced

Contribution 1

Beyond Tone Mapping

Enhanced Depiction of Tone Mapped HDR Images

Contribution II

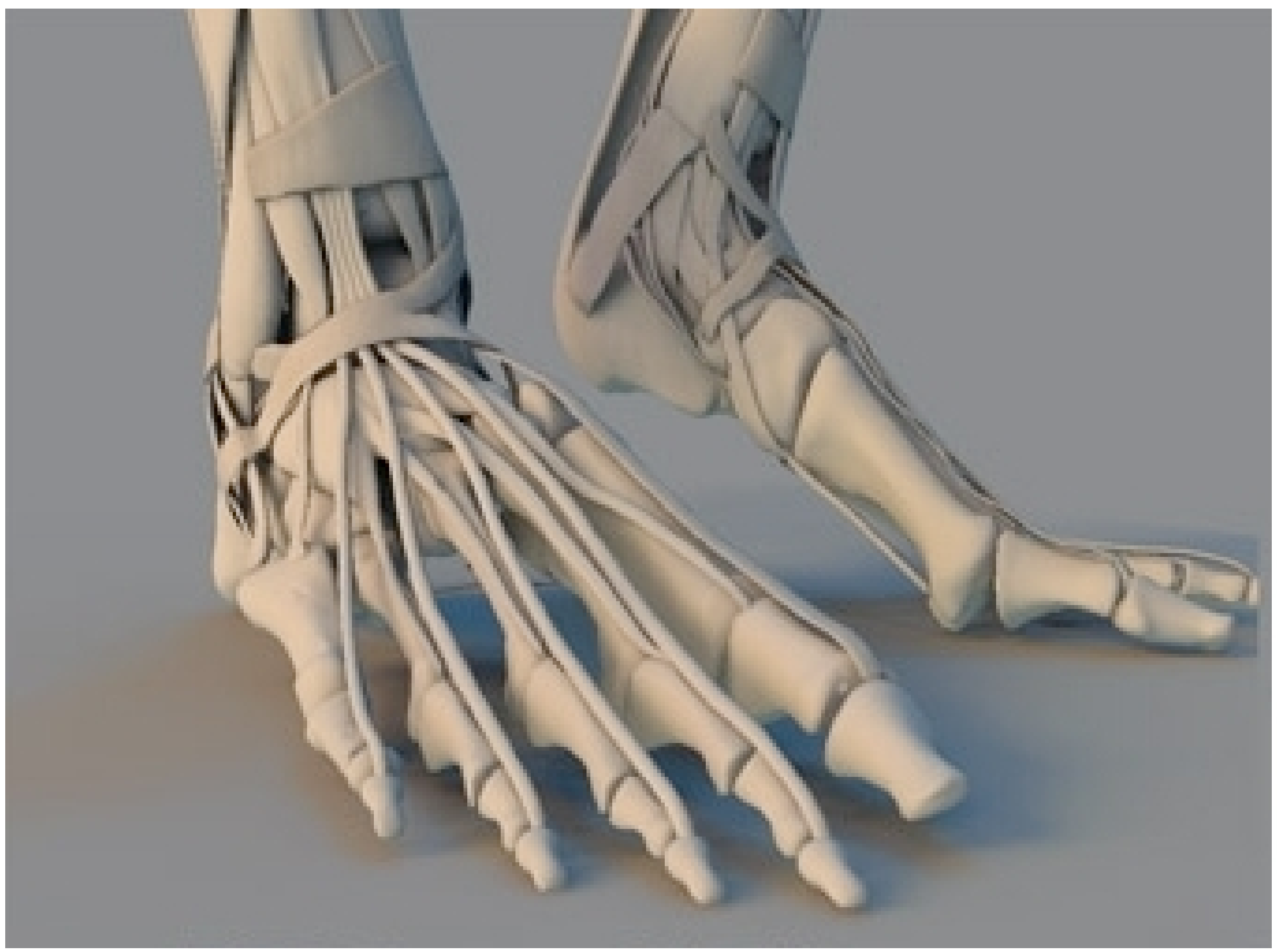
Apparent Greyscale

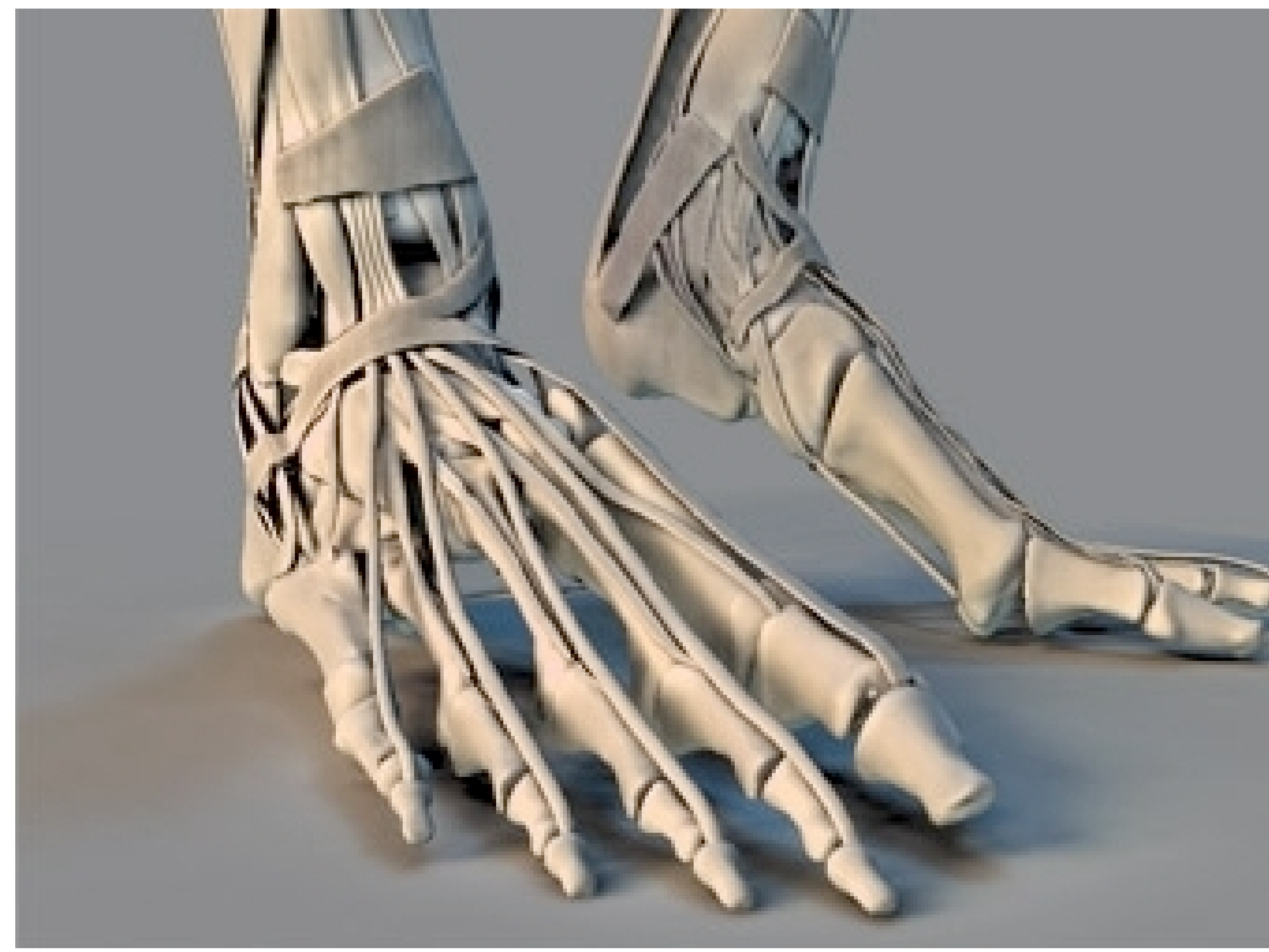
A Simple and Fast Conversion to Perceptually Accurate Images and Video

Contribution III

3D Unsharp Masking

for Scene Coherent Enhancement





Contributions

Beyond Tone Mapping

Apparent Greyscale

3D Unsharp Masking

Problem	**Tone Mapping**	**Greyscale Conversion**	**3D Rendering**
Goal	Restore lost contrast	Preserve chromatic contrast	Enhance scene contrast
Input ↓ Output	HDR/LDR image pair ↓ LDR image	Colour image/video ↓ Greyscale image/video	3D scene ↓ Rendered image/video

Enhancing Contrast Depiction

Unsharp Masking Local contrast enhancement technique, unsharp masking, can overcome these constraints by adding high-frequency contours to an image, increasing apparent contrast.

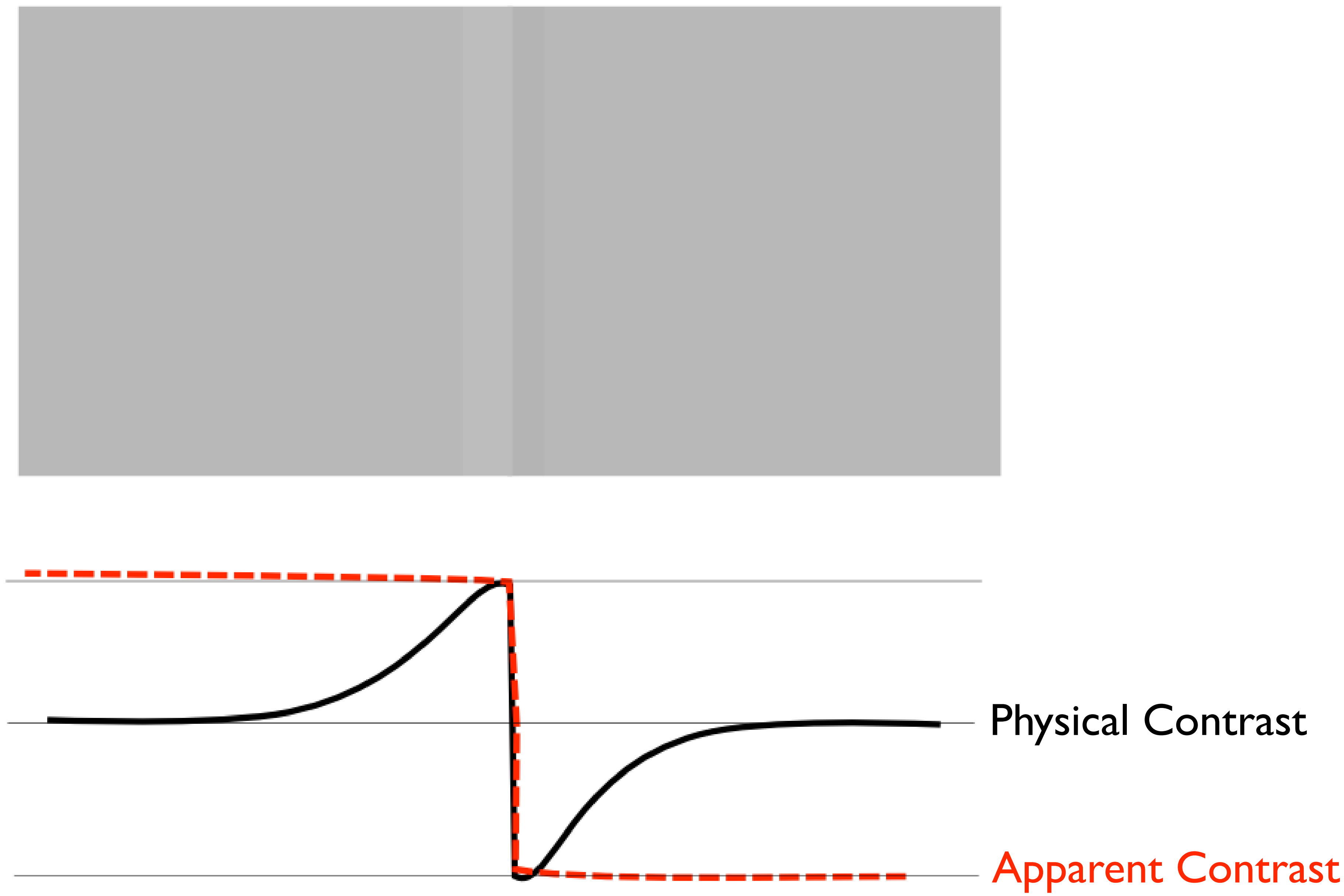
Image Enhancement via Adaptive Unsharp Masking. Polesel et al. 2000

Original

Enhanced by Unsharp Masking

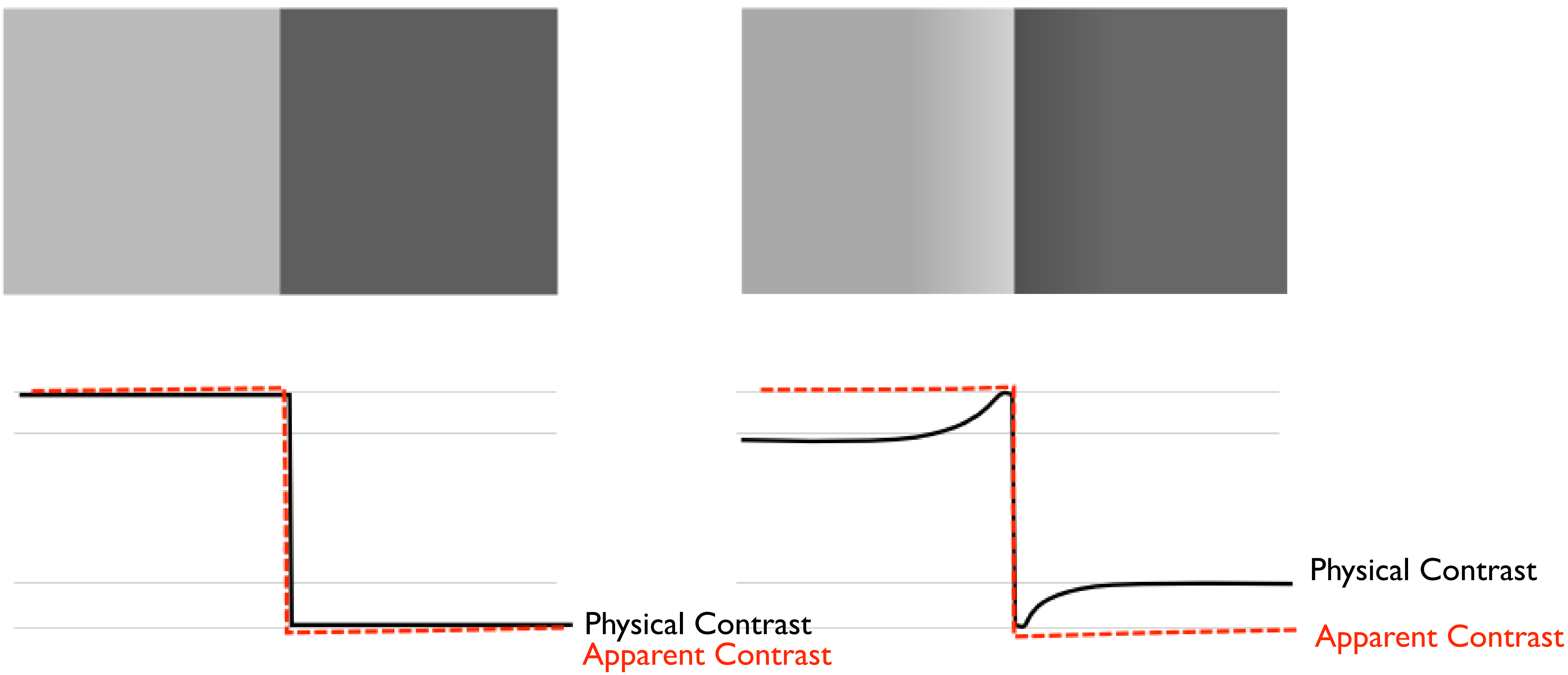
Cornsweet Contour

A contour whose luminance profile of sharp opposing peaks gradually returns to the same luminance, or to luminances of lesser contrast.



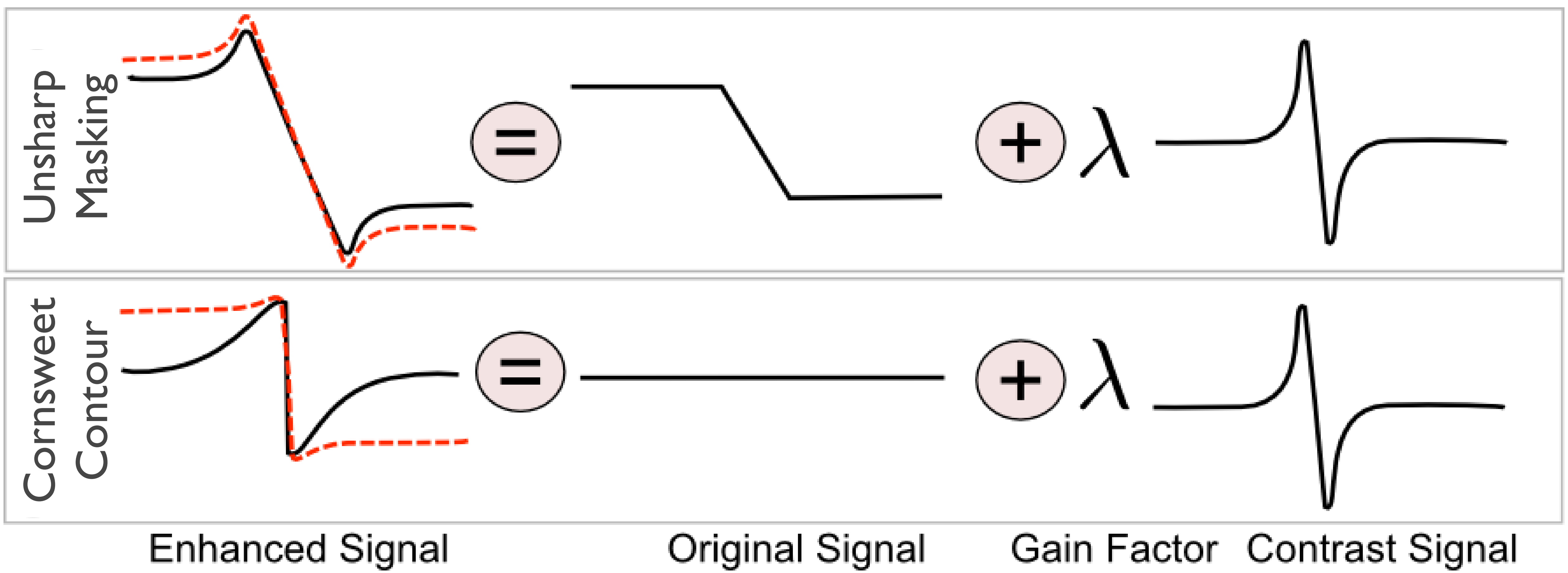
First Principle

Adding a Cornsweet contour can increase **apparent contrast** beyond the physical contrast in complex images.



Second Principle

Unsharp masking is capable of introducing Cornsweet contours, and the perceptual effect of unsharp masking can be explained by the Cornsweet illusion.



Basic Unsharp Masking

Enhanced

=

Original

+λ(

Original

-

Gaussian Blur σ

)

Unsharp Masked Signal *U*(S)

Original Signal S

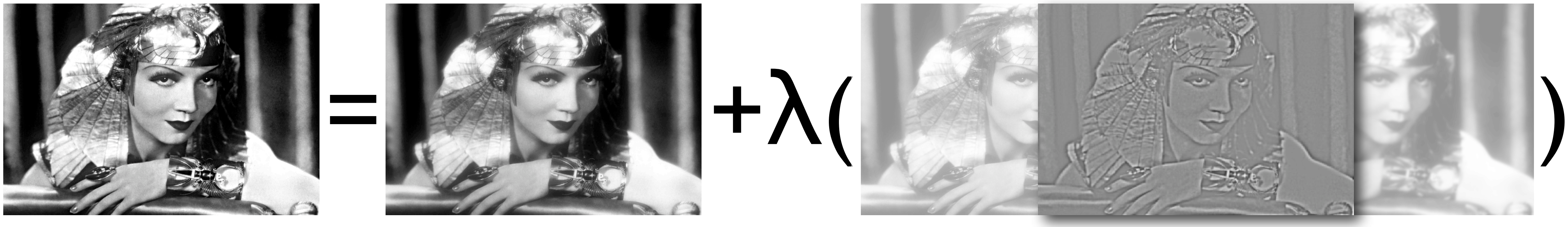
$$U(S) = S + \lambda(S - S\sigma)$$

Gain Control λ

Contrast Signal *C*(S)

Blur spatial extent σ

Basic Unsharp Masking



Unsharp Masked Signal *U*(S)

Original Signal S

$$U(S) = S + \lambda(S - S\sigma)$$

Gain Control λ

Blur spatial extent σ

Contrast Signal *C*(S)

- Difference of Gaussians approximates the Laplacian (second derivative). The contrast signal is measured by change in change in intensity (direction and magnitude).

Basic Unsharp Masking

Enhanced

=

Original

+λ(

Original

Gaussian Blur σ

Contrasts

)

Unsharp Masked Signal *U*(S)

Original Signal S

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Contrast Signal *C*(S)

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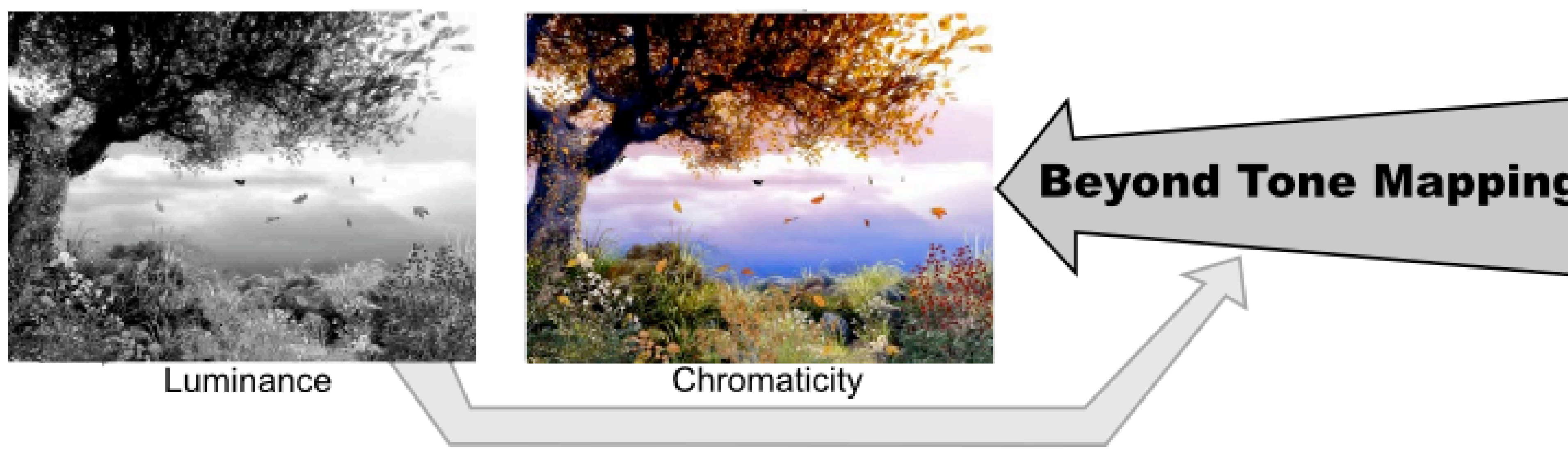
Contributions

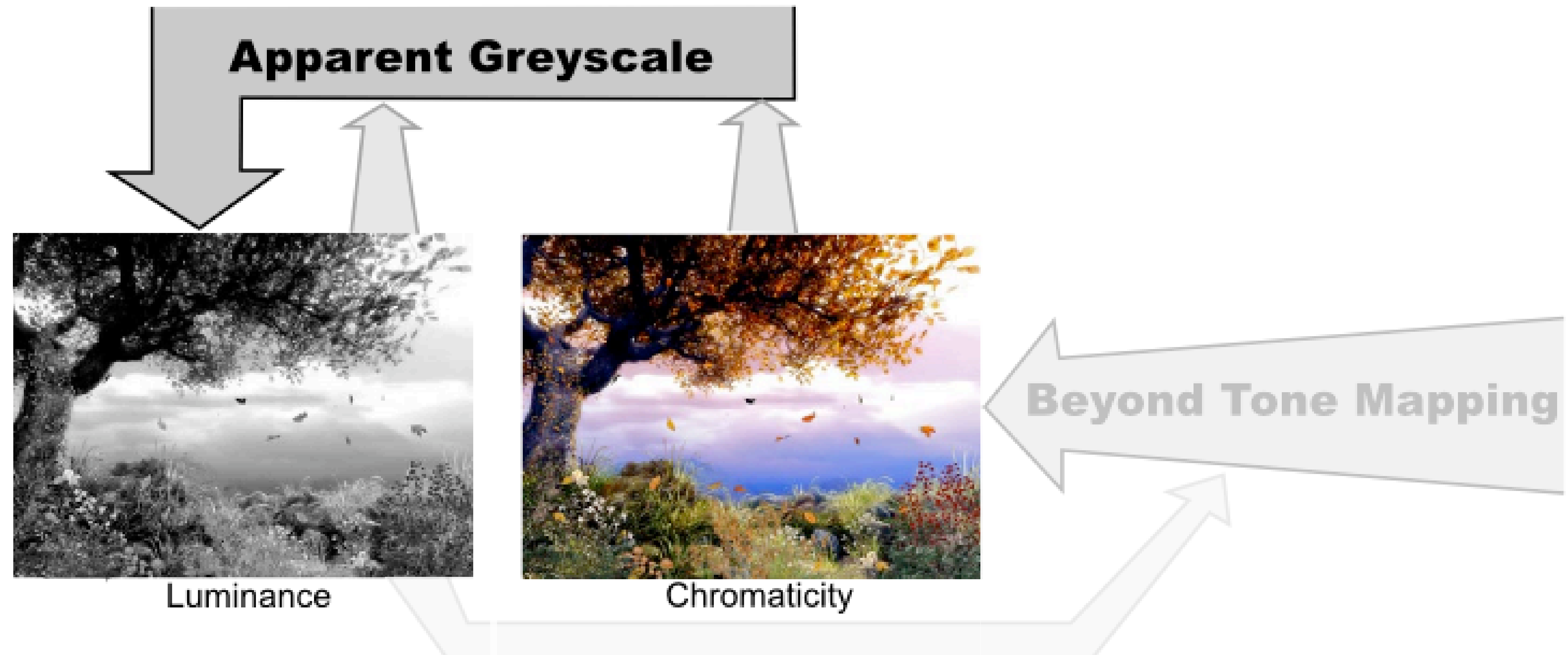


Lightness — Chromatic Channels u* and v*

$$U(I)_{LUV} = [\quad L^* \quad , u^* + \lambda_{u^*} C(Y, y), v^* + \lambda_{v^*} C(Y, y) \,]$$

Y HDR Luminance — y LDR Luminance

Contributions

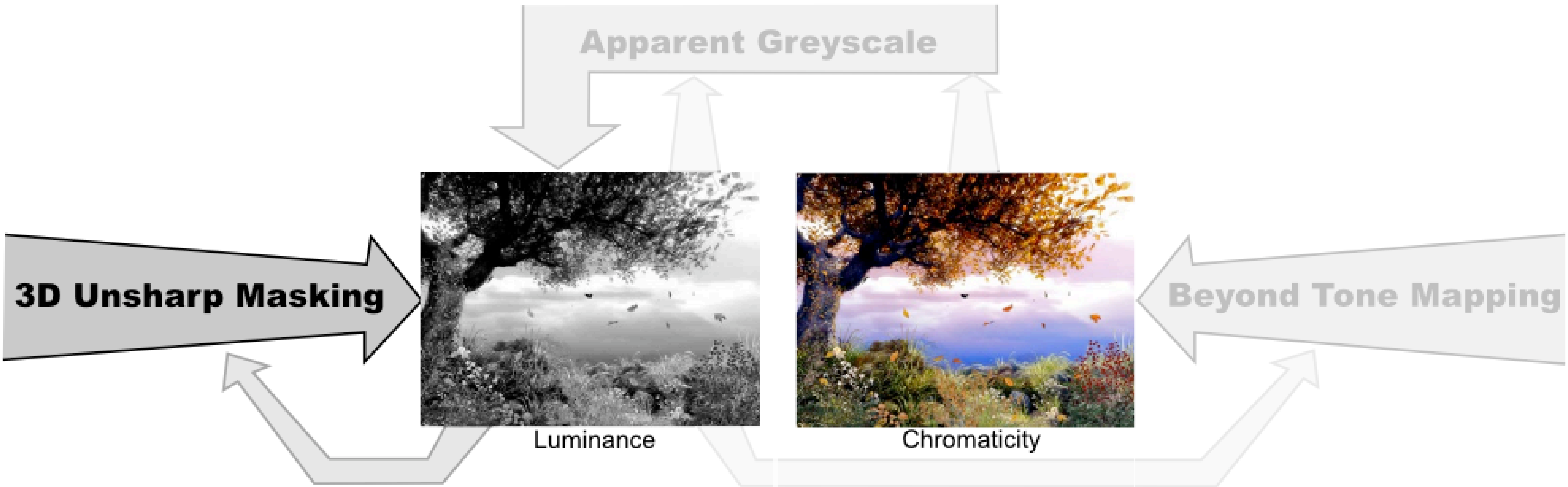


$$U(I)_{LUV} = [\; L^* \;,\; u^* + \lambda_{u^*} C(Y, y),\; v^* + \lambda_{v^*} C(Y, y) \;]$$

$$U(G)_{LAB} = [\; G_{L^*} + \lambda C(L^*),\; a^* \;,\; b^* \;]$$

Converted Greyscale Lightness   Strength from Chromatic Difference

Contributions



$$U(I)_{LUV} = [\ L^*,\ u^* + \lambda_{u^*}C(Y, y),\ v^* + \lambda_{v^*}C(Y, y)\ ]$$

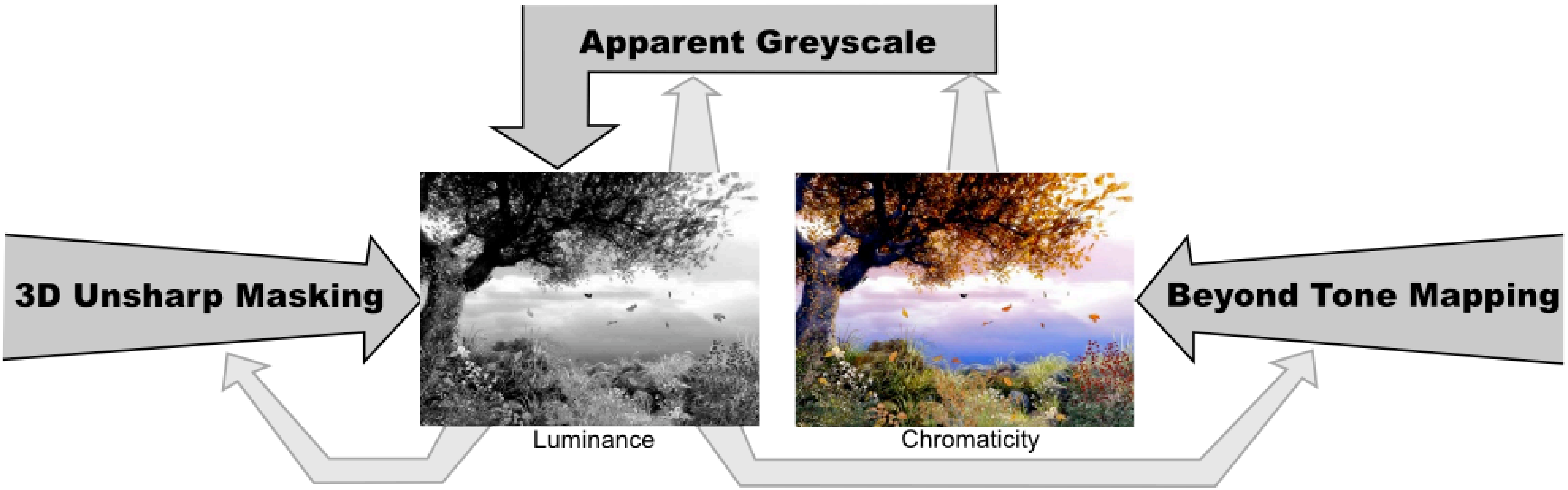
$$U(G)_{LAB} = [\ G_{L^*} + \lambda C(L^*),\ a^*,\ b^*\ ]$$

$$U(S)_{LAB} = [\ L^* + \lambda C(S_{L^*}),\ a^*,\ b^*\ ]$$

3D Rendered Lightness

Lightness over the 3D surface

Contributions



$$U(I)_{LUV} = [\ L^*,\ u^* + \lambda_{u^*} C(Y, y),\ v^* + \lambda_{v^*} C(Y, y)\ ]$$

$$U(G)_{LAB} = [\ G_{L^*} + \lambda C(L^*),\ a^*,\ b^*\ ]$$

$$U(S)_{LAB} = [\ L^* + \lambda C(S_{L^*}),\ a^*,\ b^*\ ]$$

Beyond Tone Mapping

Restoring Apparent Contrast to Tone Mapped Images

High Dynamic Range Images

- HDR images capture full range of luminance present in real world scenes.
  - details in both dark and light regions
  - precise luminance information

Viewing different ranges of values within an HDR image

Tone Mapping

- For display, need to create LDR depictions of HDR images (loss of contrast information).
- Tone mapping operators map from HDR to LDR
  - Global Operators: loyal reproduction of luminance range
  - Local Operators: preservation of details

Photoreceptor Operator

Bilateral Filtering

Gradient Domain Compression

Purpose

- Enhance low dynamic range (LDR) images resulting from tone mapped high dynamic range (HDR) images:
  - Restore perceived dynamic range (depth)
  - Restore visibility of details (texture, contours)

LDR

Enhanced LDR by Chromatic Unsharp Masking

Unsharp Masking the Chromatic Channels

$$U(I)_{LUV} = [\quad L^* \quad, u^* + \lambda_{u^*} C(Y, y), v^* + \lambda_{v^*} C(Y, y)]$$

- Use Difference of Gaussians (DoG) to determine contrast signals. This approximates the second derivative (Laplacian).

$$C(Y) = \log_{10} Y - \log_{10} Y_\sigma$$

Contrast of HDR Luminance

$$C(y) = \log_{10} y - \log_{10} y_\sigma$$

Contrast of LDR Luminance

- Compare $C(Y)$ and $C(y)$ to find magnitude of restoration.
- Need polarity of chromaticity. Make colourful side more so.

Unsharp Masking the Chromatic Channels

$$U(I)_{LUV} = [\quad L^* \quad , u^* + \lambda_{u^*} C(Y, y), v^* + \lambda_{v^*} C(Y, y) \,]$$

- Use Difference of Gaussians (DoG) to determine contrast signals. This approximates the second derivative (Laplacian).

$$C(Y) = \log_{10} Y - \log_{10} Y_\sigma$$

Contrast of HDR Luminance

$$C(y) = \log_{10} y - \log_{10} y_\sigma$$

Contrast of LDR Luminance

$$C(Y, y) = \text{sign}(C^* - C^*_\sigma)\ |\,C(Y) - C(y)|$$

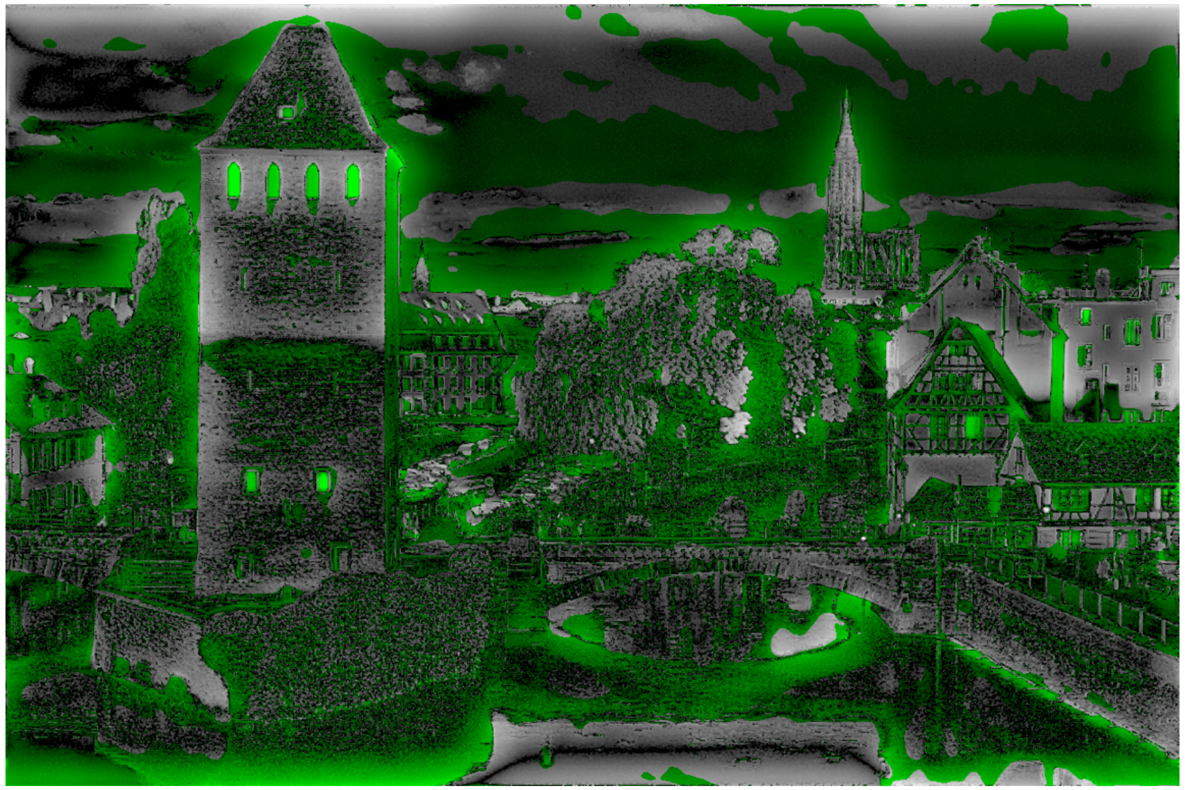
Contrast of HDR Chroma

Difference of HDR and LDR Contrast

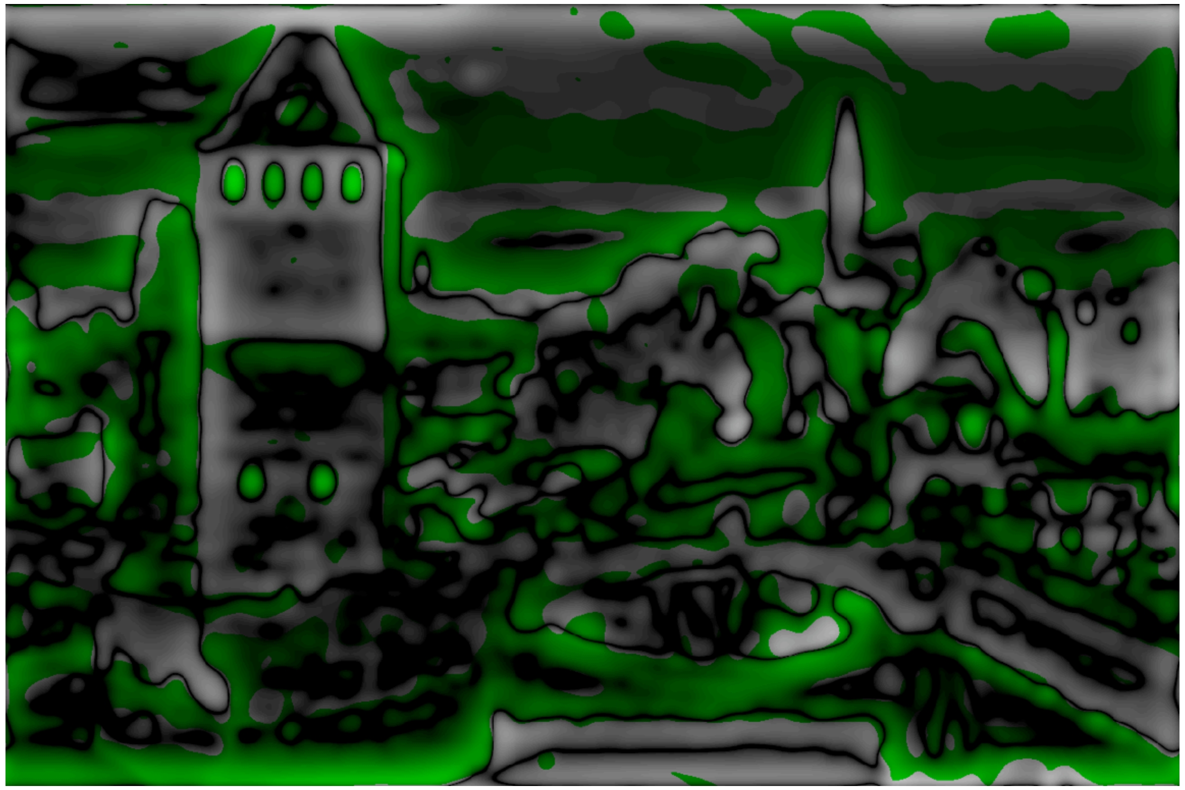
Two-scale: Detail and Base Levels

Luminance

Base Layer Luminance (Bilaterally Filtered)

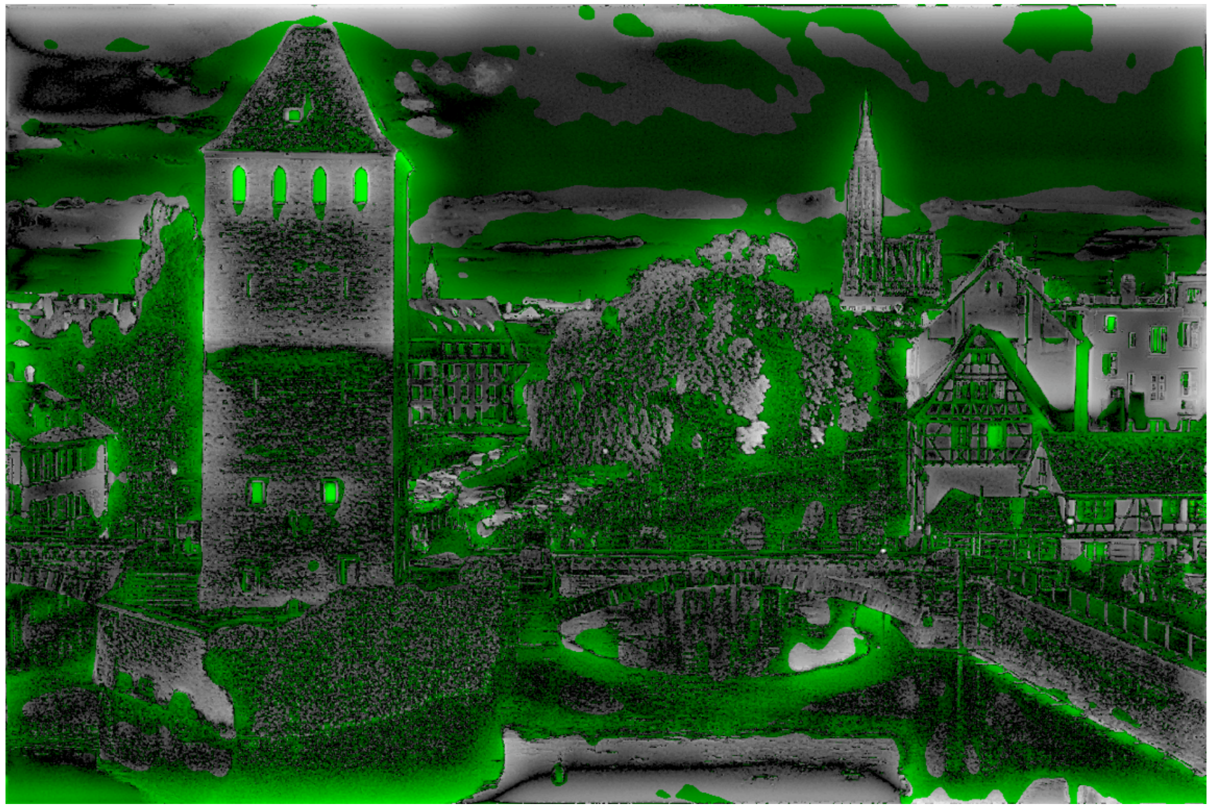


Details Contrast Signal



Base Contrast Signal

Results



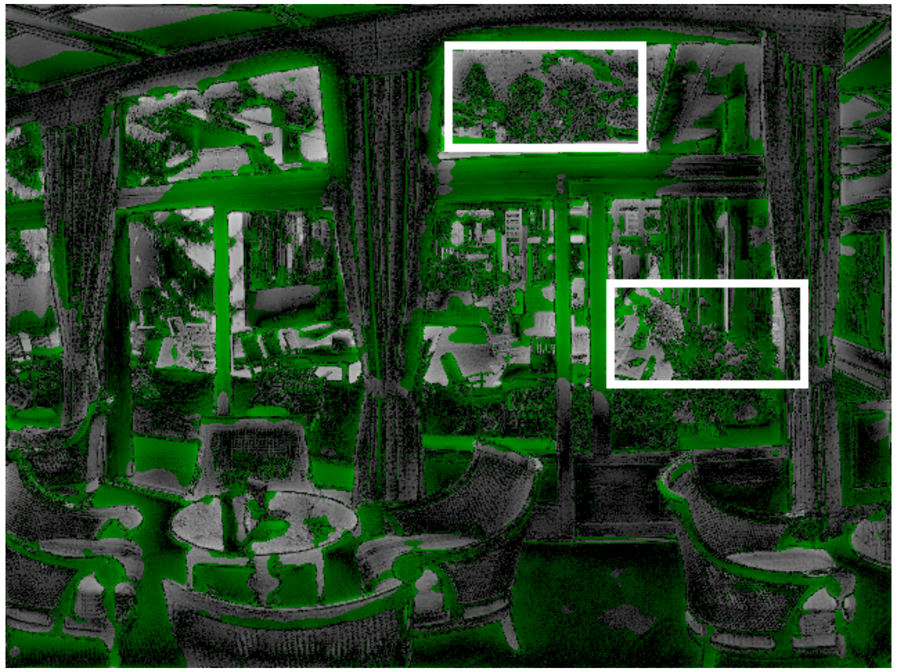
Original LDR

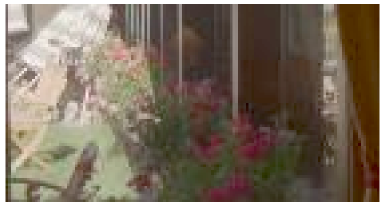
Beyond Tone Mapping

Results

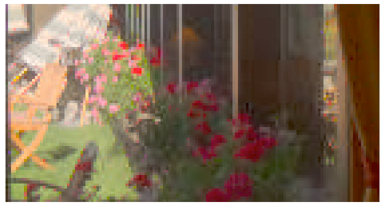
Original LDR

Beyond Tone Mapping





Original LDR



Beyond Tone Mapping

Original LDR

Beyond Tone Mapping

Wish List

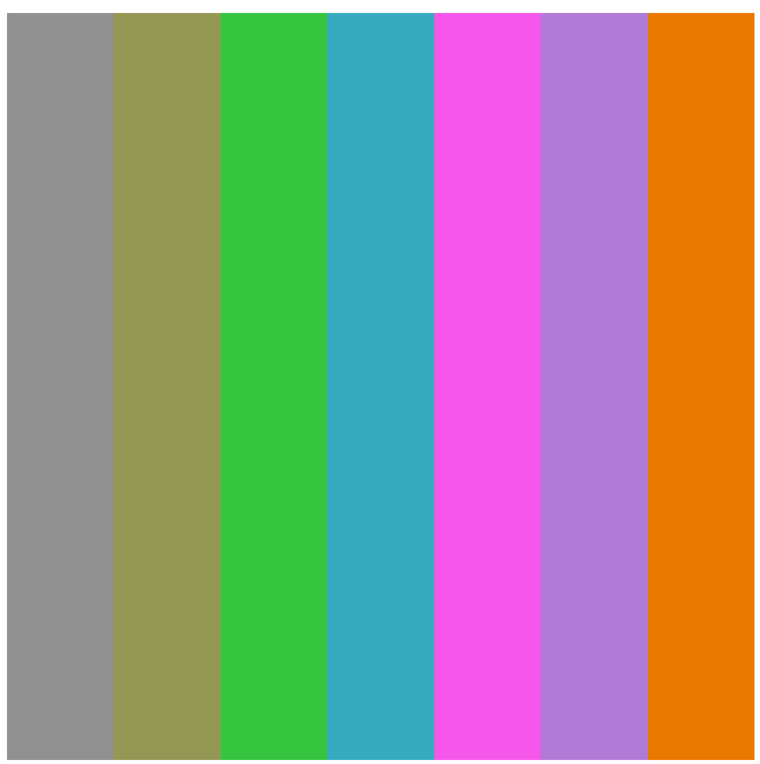
- Compare the HDR and LDR luminance contrasts in just-noticeable-differences (JND).
- Also, relate the lost contrast and restored colour contrasts in JND.
- Expand to multi-scale for more control over restoration.
- Measure perceived colour changes due to tone mapping and try to restore them as well.

Apparent Greyscale

Greyscale Conversion of Images and Video

Challenges to greyscale mapping

- **Map chromatic to achromatic (3D to 1D)**: reduce information to a single channel.
- **Maintain Discriminability**: in mapping, apparent colour differences may be reduced or even lost.



Colour RGB

The GIMP Conversion

Appearance is more than discriminability

Our algorithm creates a *perceptually accurate* version of the colour original by preserving:

- **Range**: original values' range and average luminance
- **Apparent Order:** colours ordered according to their appearance using apparent brightness.
- **Discriminability:** local contrasts neither lost nor exaggerated
- **Image Features:** local details unchanged

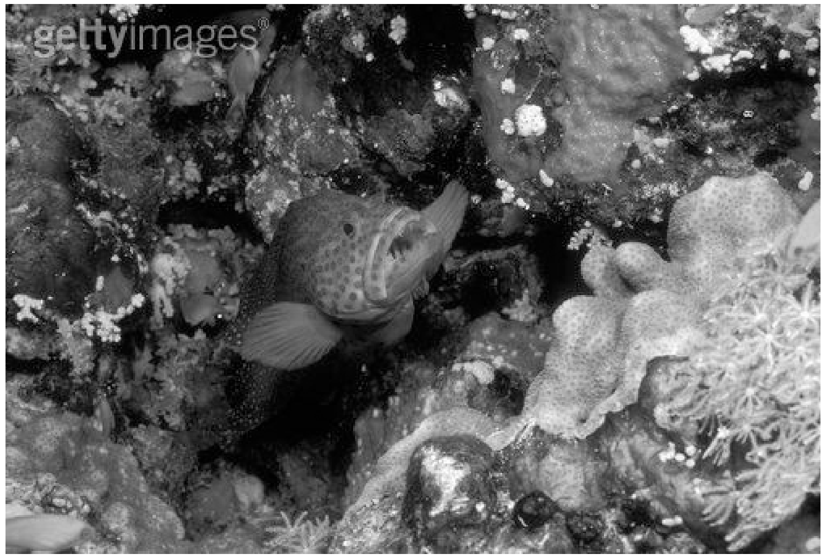
Step 1: Global Mapping to Lightness

- A colour's appearance depends *mostly* on its luminance.
- But, it *also* depends on its hue, saturation / chromaticity, known colour effects, surround, environment, etc...

Colour

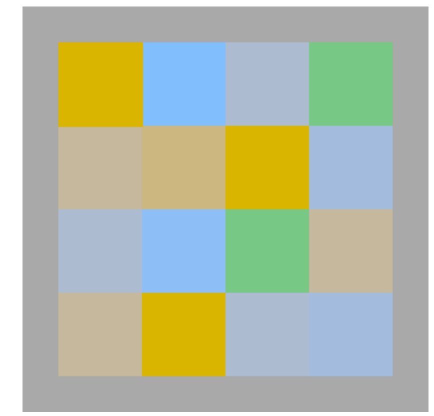
Luminance

Chromatic Lightness



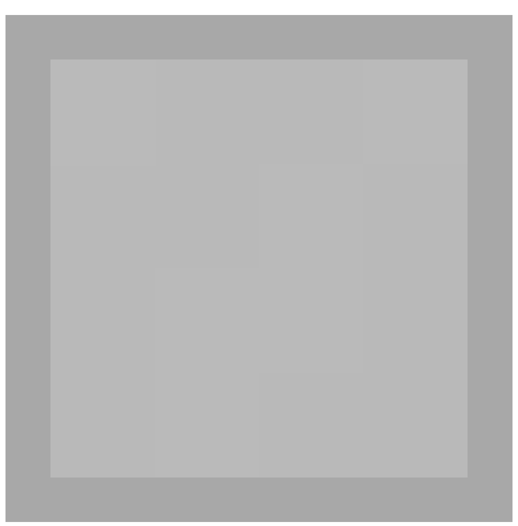
Lightness Models of Colour Appearance

- *Lightness* is the perceived brightness of object compared to a similarly illuminated white.
- Achromatic perceptual response to colour.

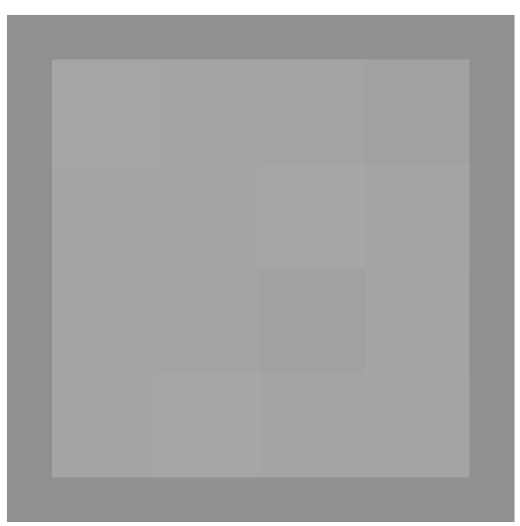


Colour

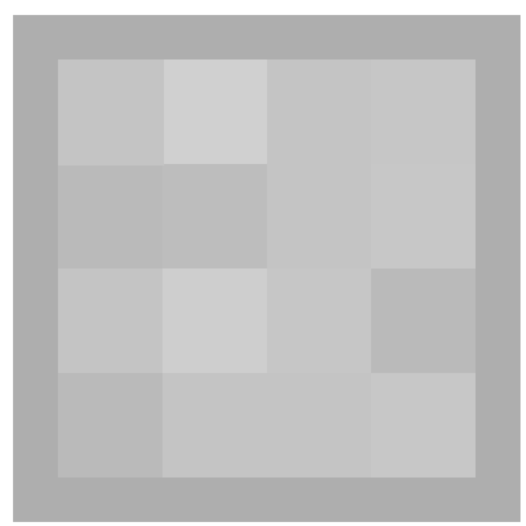
- From colour theory, several lightness models, such as:



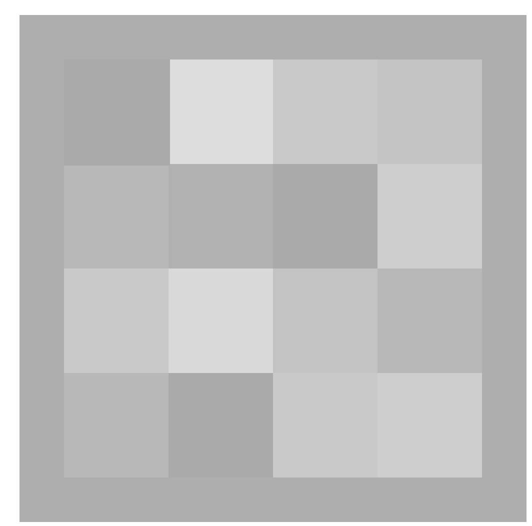
Lightness L^*
CIE



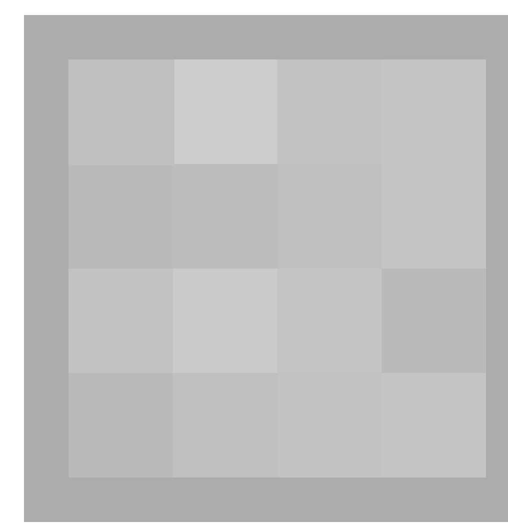
CIECAM '02
CIE



L^{**}
Fairchild et al.



$L^*_{N\_VCC}$
Nayatani et al.

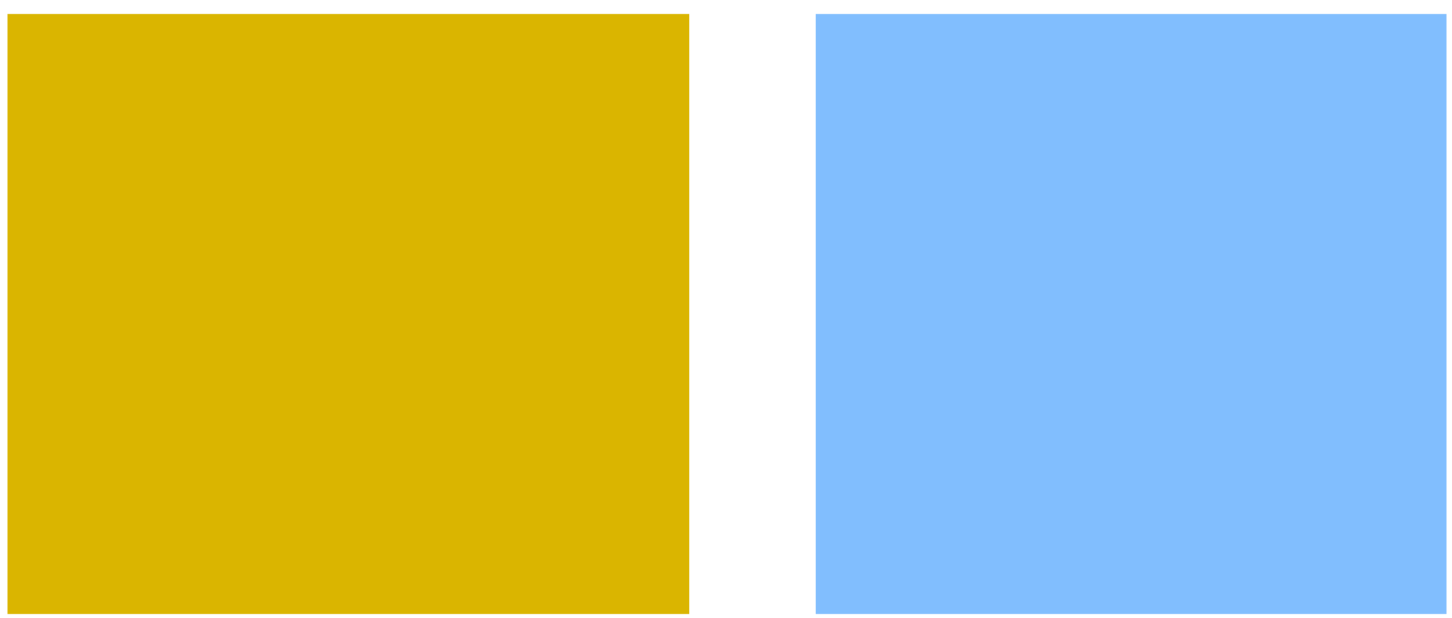


$L^*_{N\_VAC}$
Nayatani et al.

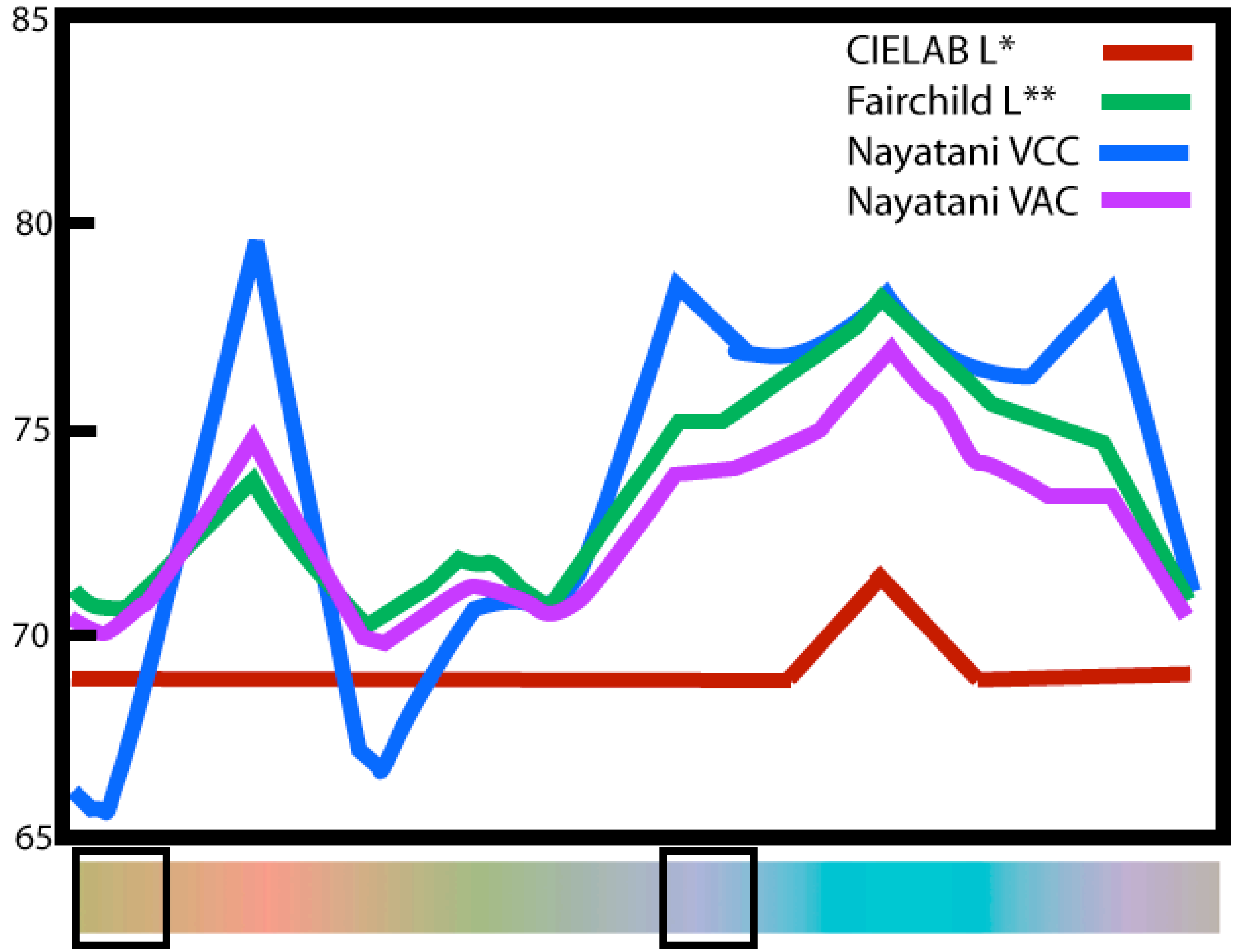
The Helmholtz-Kohlrausch Effect

- For greyscale conversion, an important issue in colour appearance is the Helmholtz-Kohlrausch effect:

Given two iso-luminant colours, the more colourful appears brighter.



Lightness Models With H-K Effect



By accounting for this effect, the lightness of nearly isoluminant colours has greater variation.

Step 1: Global Mapping to Lightness

- The L^*_N (or L^*_{NVAC}) chromatic lightness metric is defined in CIELUV colour space.
- Adds a H-K effect corrective term to L* lightness.

Chromatic Lightness

CIELUV Lightness

$$L^*_N = L^* + (H_\theta \, S_{uv}) L^*$$

Hue Quadrant
H-K effect's strength according to hue.

Chromatic Saturation
H-K effect's strength according to colourfulness.

Simple estimation methods for the Helmholtz-Kohlrausch effect. [Nayatani et al., Color Res. Appl., 1997]

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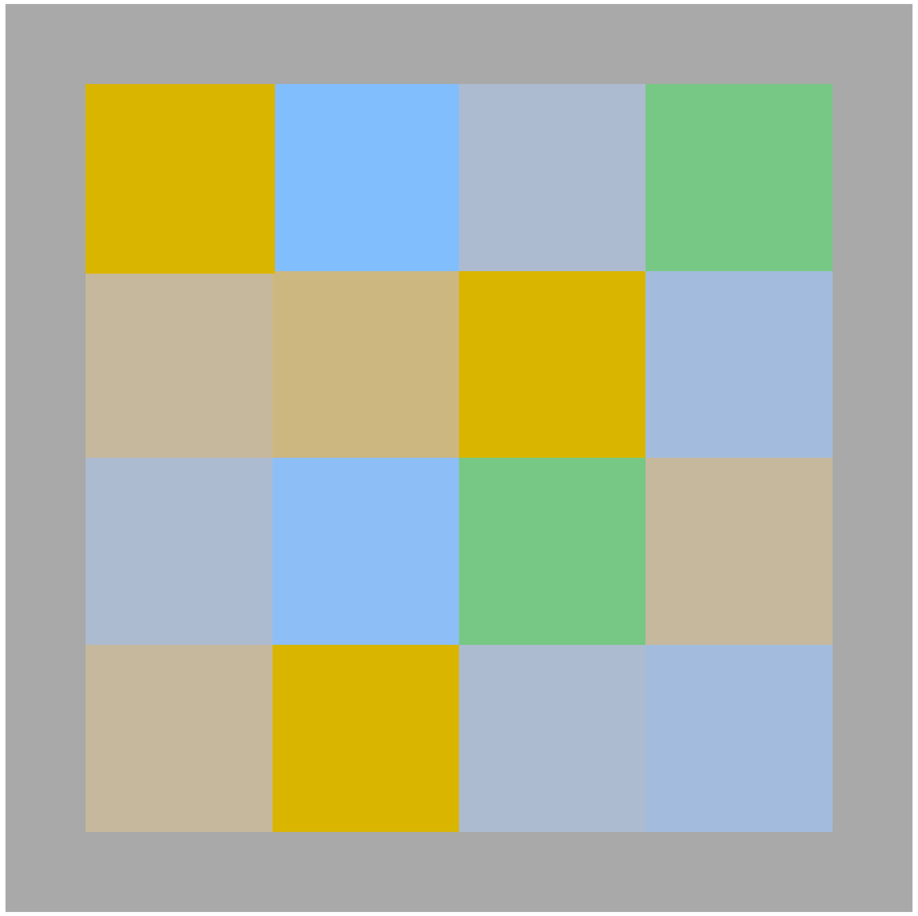
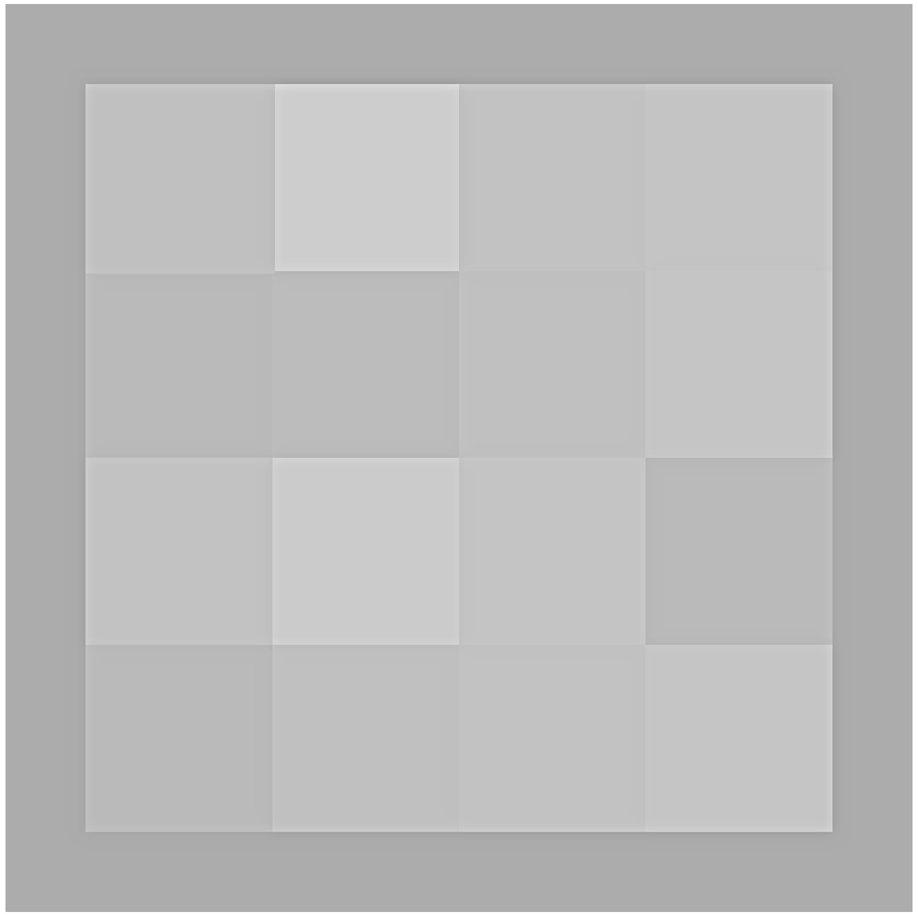
- Global Mapping: $I_{RGB} \rightarrow I_{LUV} \rightarrow I_{L^*_N} \rightarrow G$

Lost Discriminability

- The global mapping solves the problems of perceptually correct colour ordering, matching dynamic range, detail preservation - however, **discriminability** may be inadequate.



Original I



G

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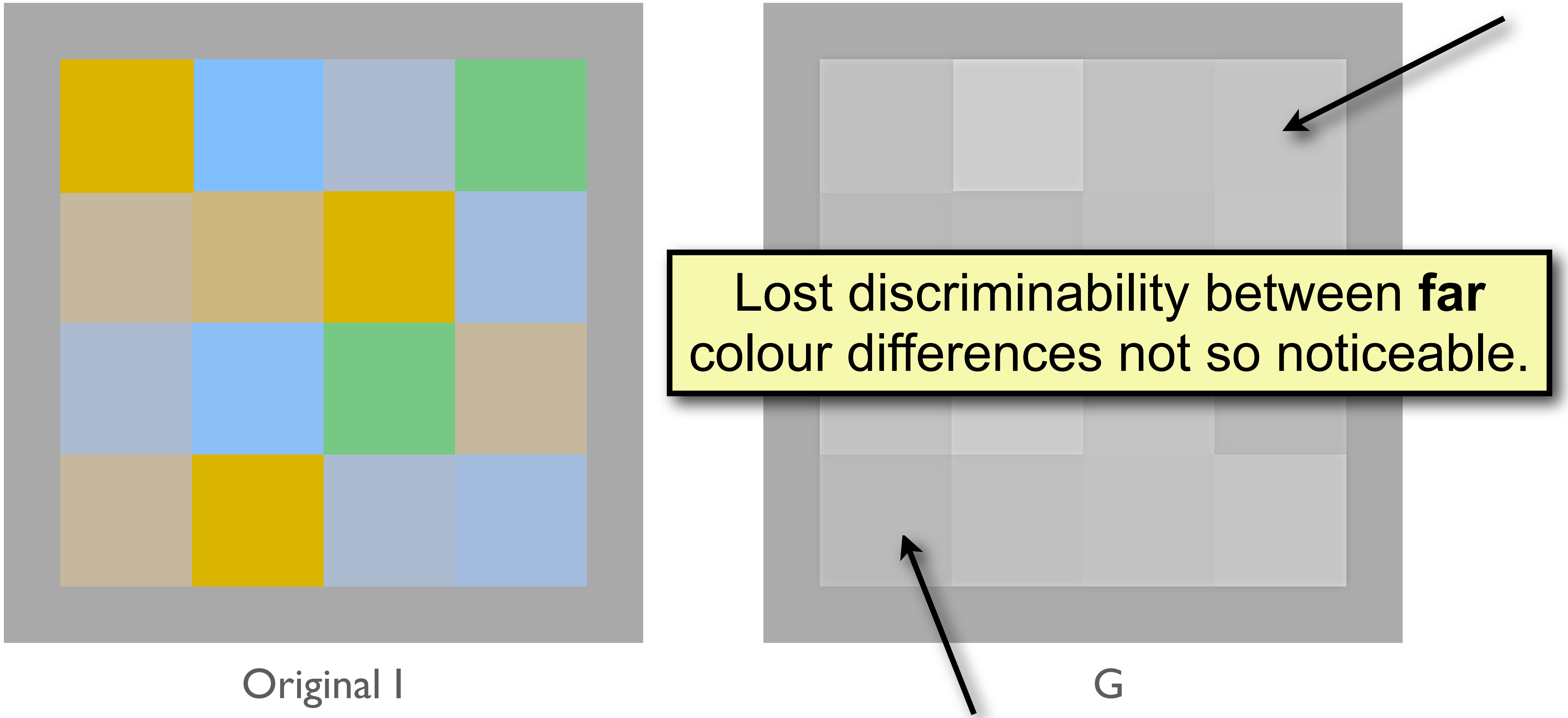

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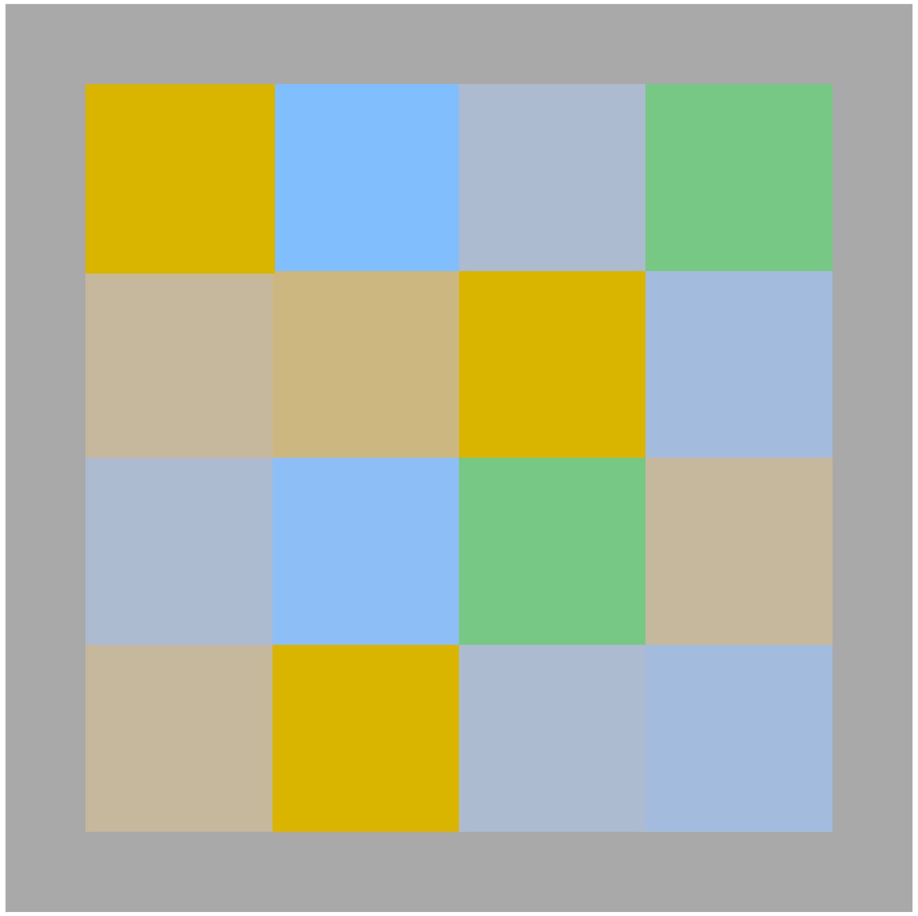
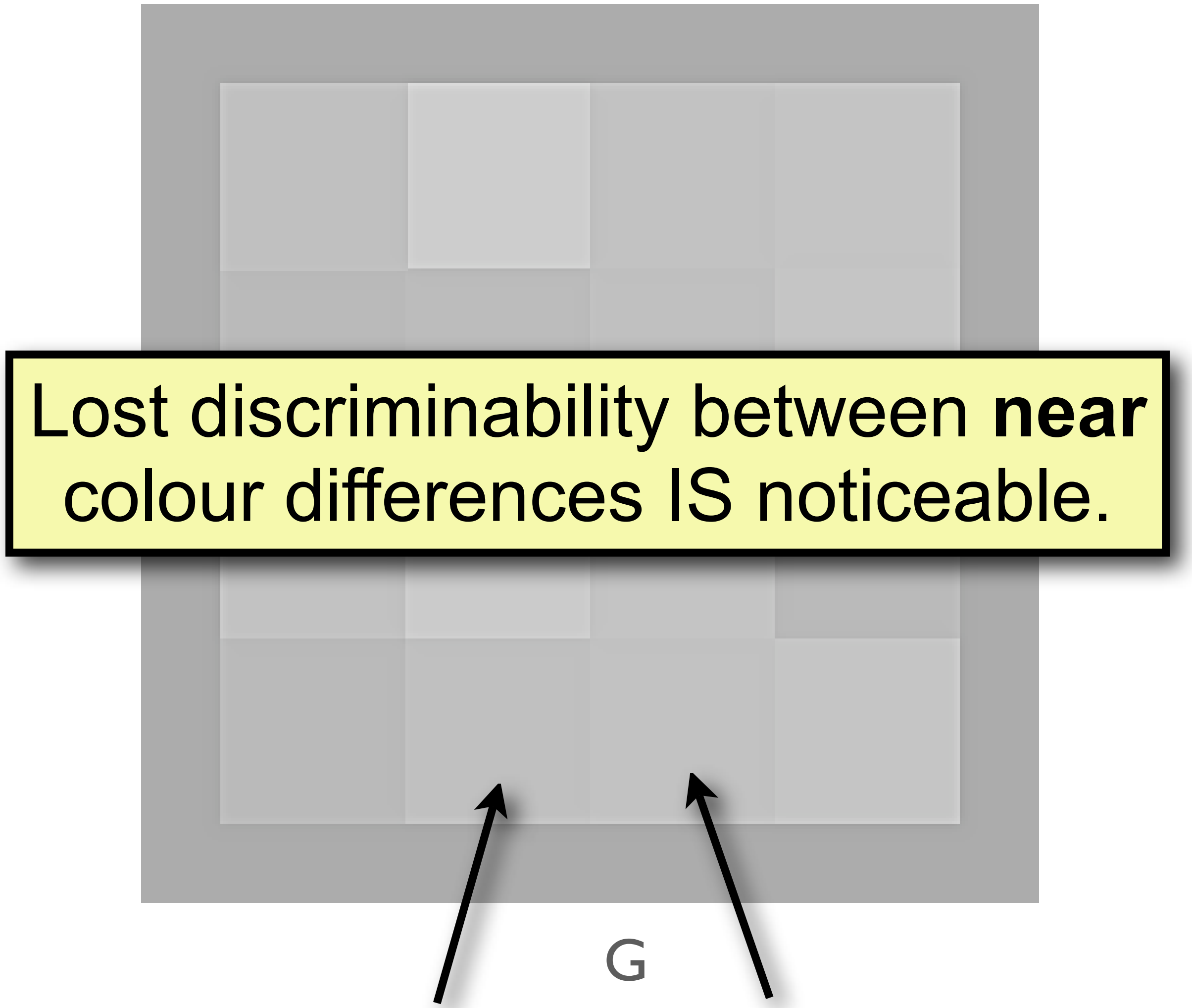


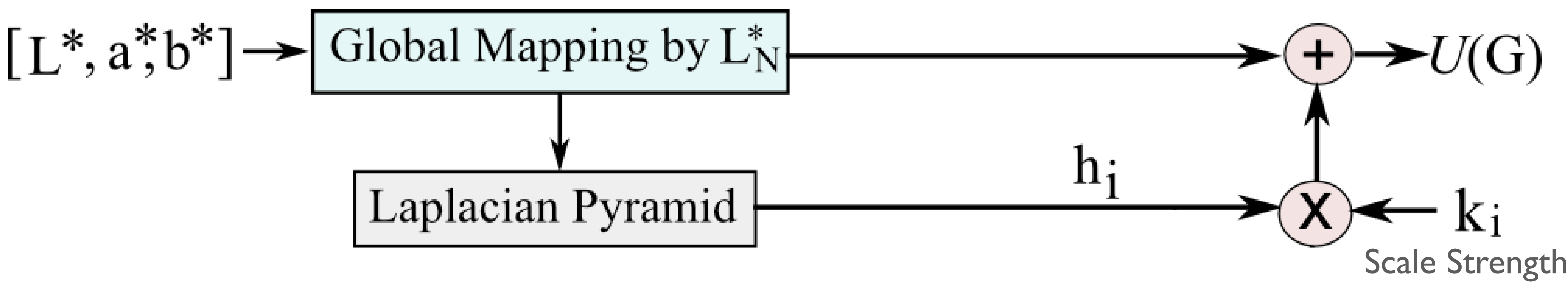
Original I

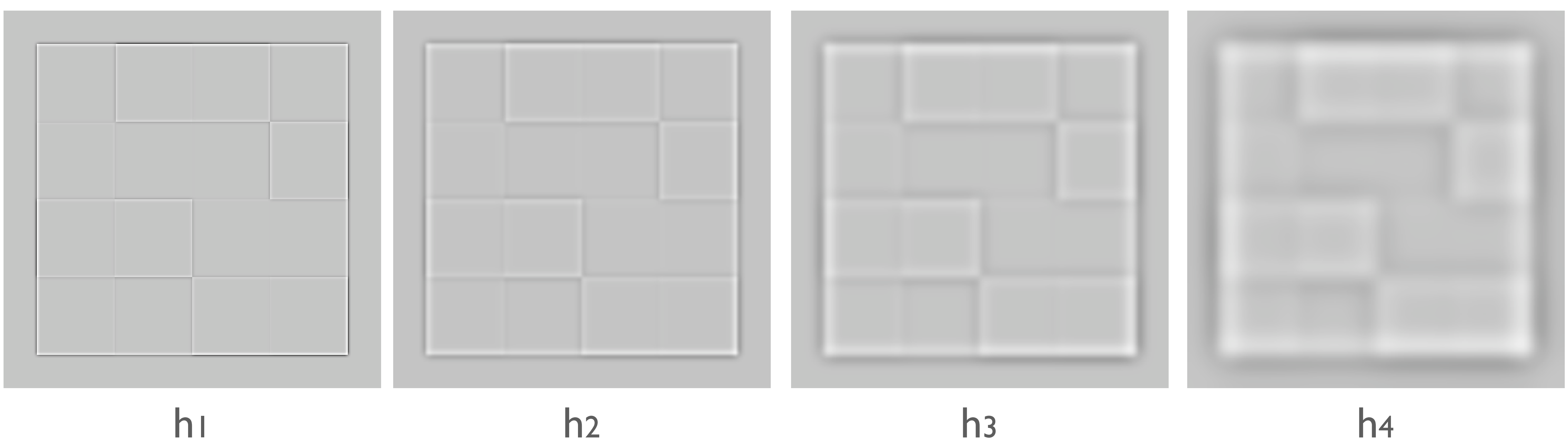


G

Step 2: Adjust Local Chromatic Contrast

- In CIE LAB, construct Laplacian pyramids for the original and greyscale images.





Up-sampled Bandpass Images

Step 2: Adjust Local Chromatic Contrast

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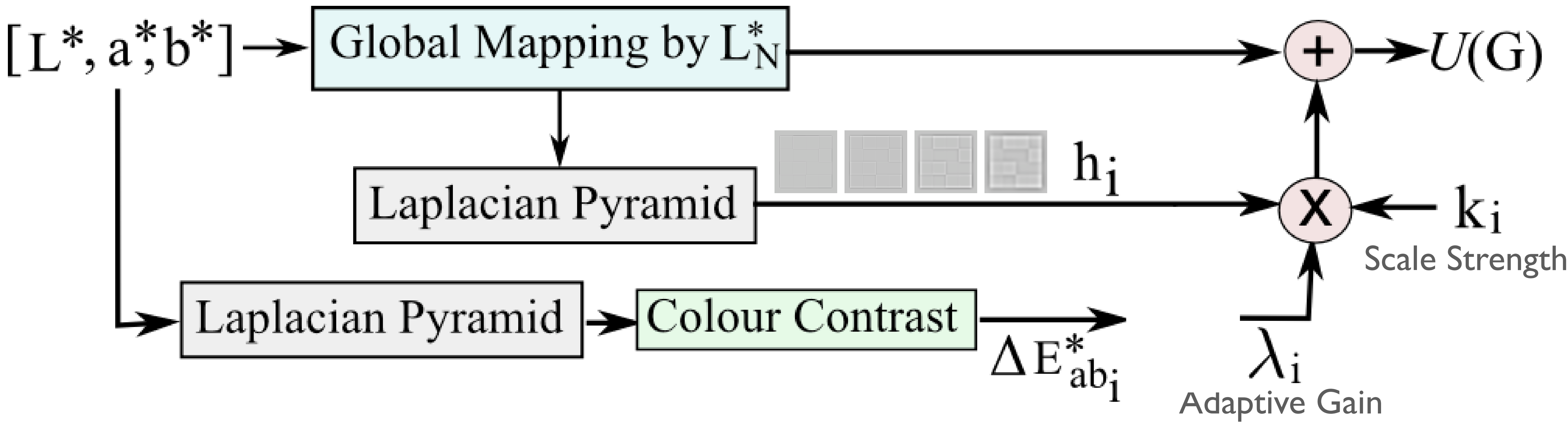
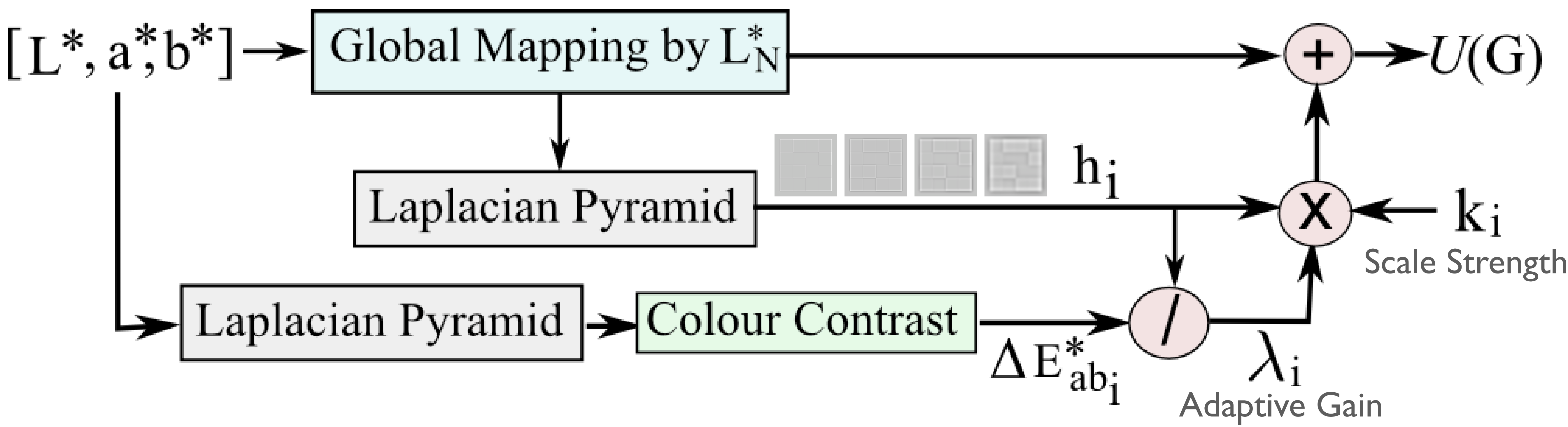


- Use chromatic contrast to weight strength of grey image contrast signal.

Step 2: Adjust Local Chromatic Contrast

- In CIE LAB, construct Laplacian pyramids for the original and greyscale images.



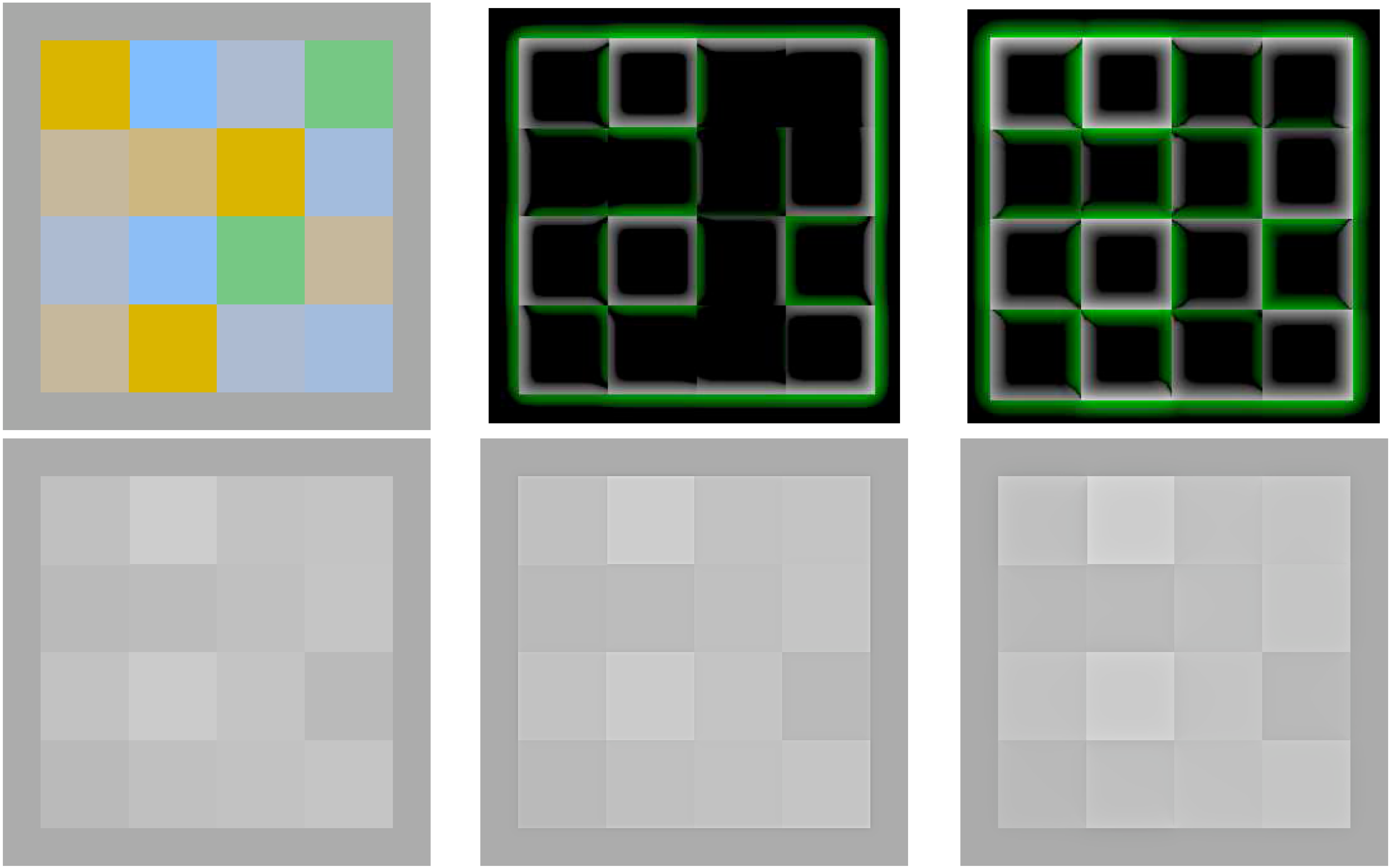
Colour Contrast

$$\lambda_i = \left(\frac{\Delta E(h_i(I))}{|h_i(G_{L^*})|} \right)^p$$

Non-linear scaling parameter

Greyscale Contrast

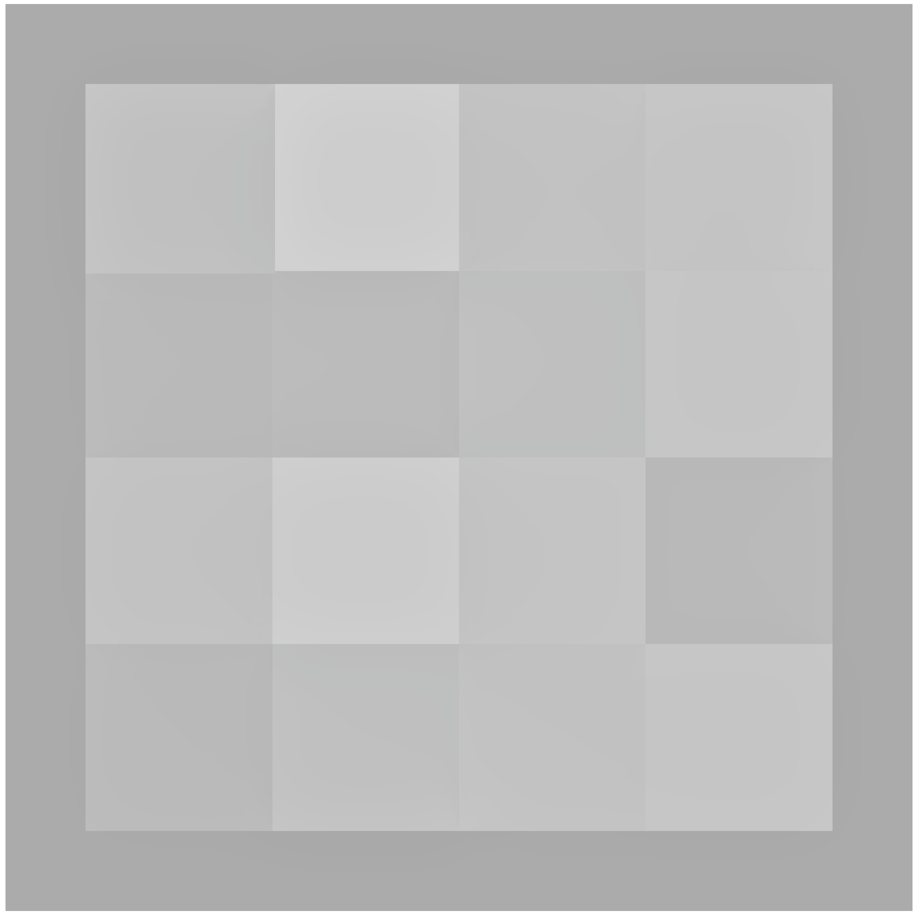
Where Contrast Is Gained



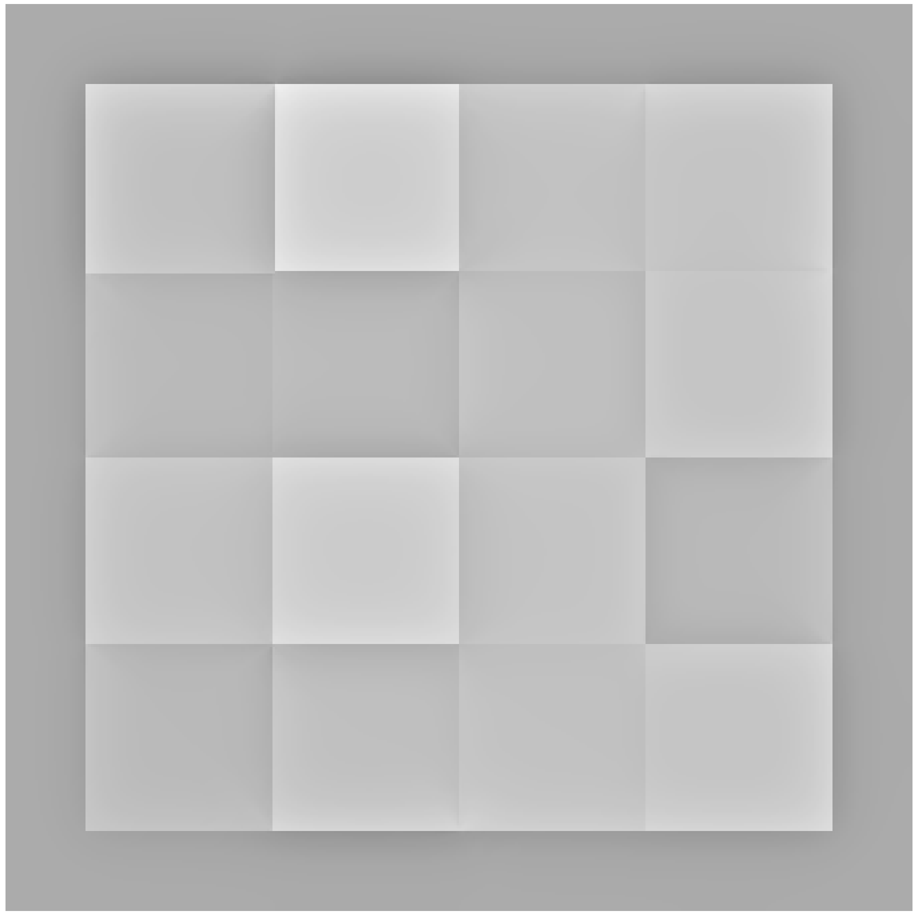
G   Basic Unsharp Masking of G   Chromatic Enhancement of G

Multiscale Strengths

- **Parameters k_i at each bandpass level** controls the strength of the enhancement, and thus the resulting discriminability.
- User choice made depending on intended display conditions.



k = {0.1, 0.1, 0.1, 0.1}



k = {1, 1, 1, 0.6}

Enhancement of Weak Contrasts

- **Parameter p** remaps the gain so weaker contrasts can be emphasized without exaggerating stronger contrasts.

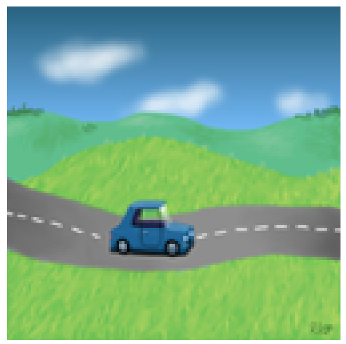
$$\lambda_i = \left(\frac{\Delta E(h_i(I))}{|h_i(G_{L^*})|} \right)^p$$

- Setting p depends on the range of contrast strengths in the original image.

p = 0.1

p = 1.0

Discriminating Isoluminant Colours



Original

Luminance Y

Apparent Greyscale

- ‘Iso-light’ colours are possible, but
  - are perceptually very similar colours
  - differ only by hue, not chromaticity

Accurate Colour Appearance

Original

Luminance Y

Apparent Greyscale

Consistent Colour Ordering

Colour Originals Ordered by Increasing Brightness

Apparent Greyscale

Impression Sunrise

Original

Gimp Greyscale

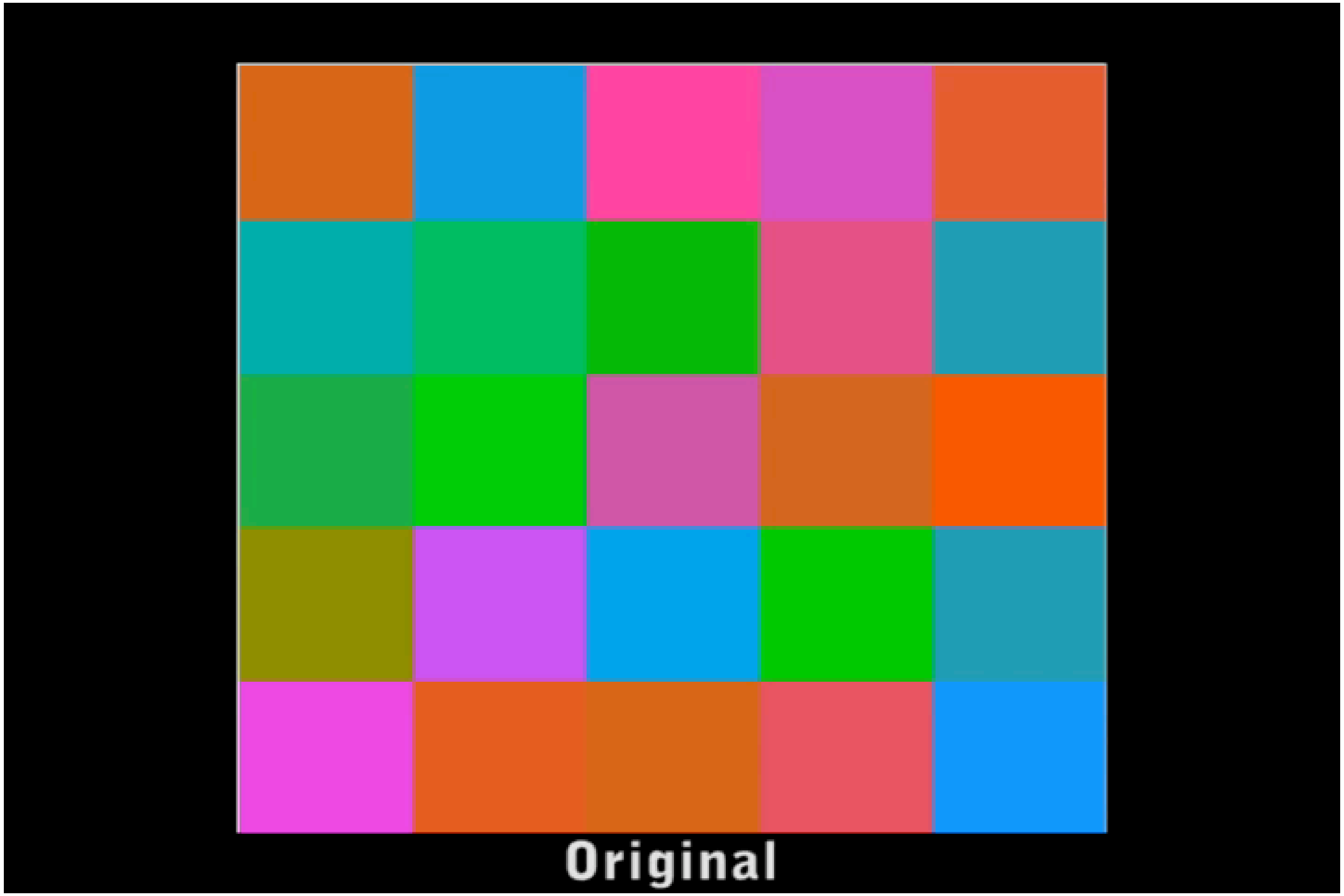
Impression Sunrise

Original

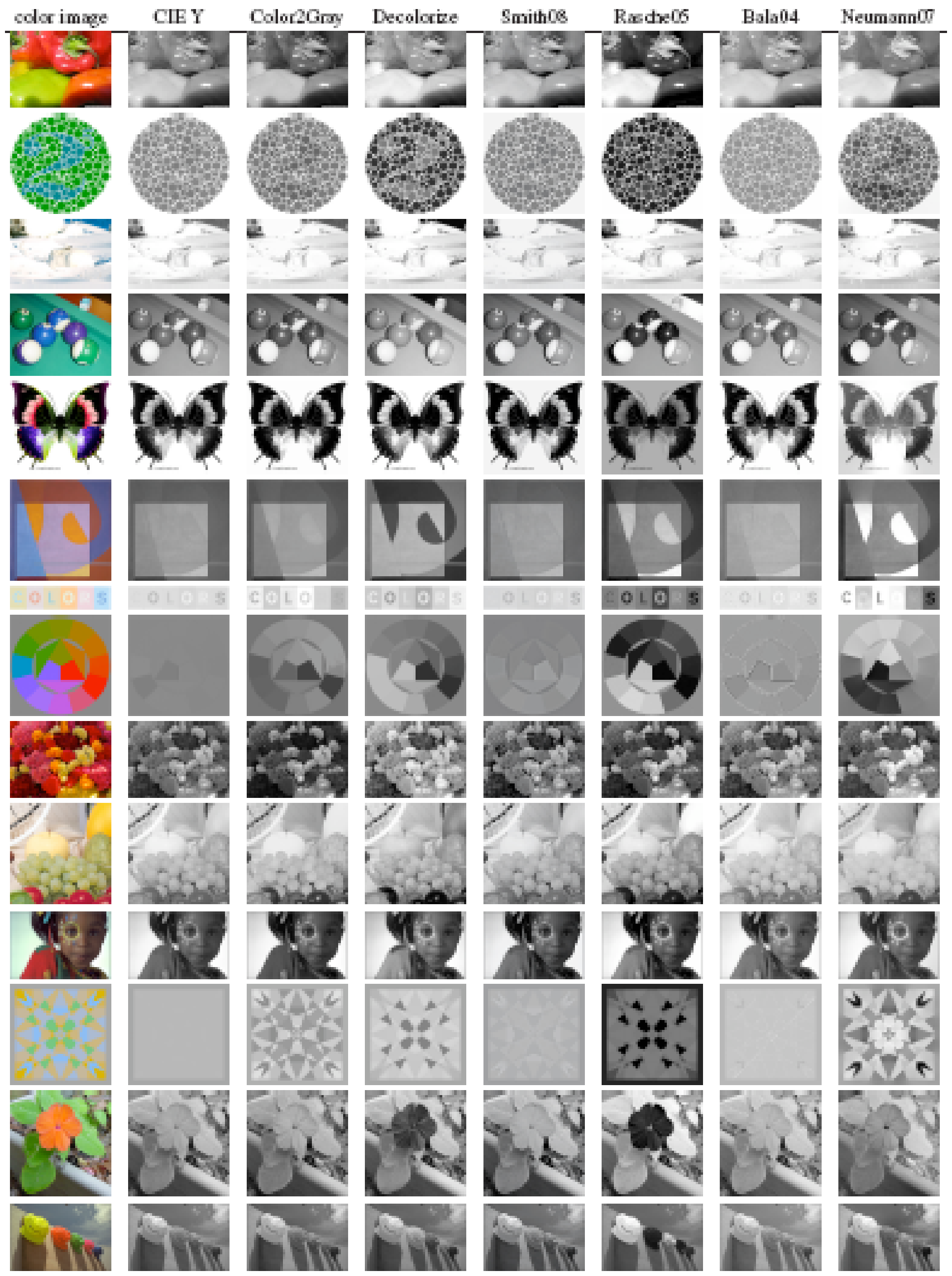
Apparent Greyscale

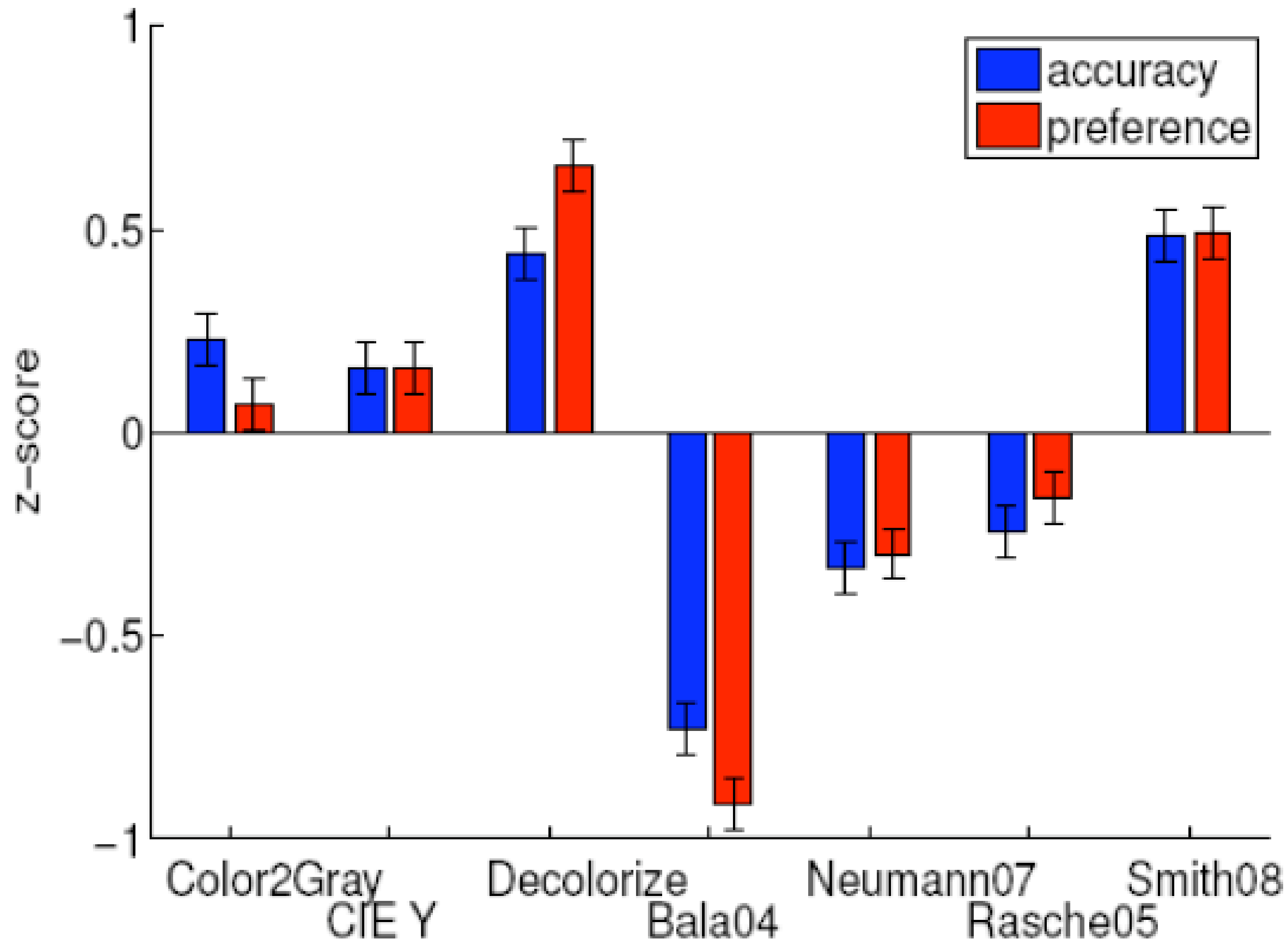
Video to Greyscale

- Very fast algorithm, no optimizations required.
- First perceptually accurate method suitable for video.



Perceptual Evaluation by Cadik et al.





Conclusions & Wish List

- This paper shows that a simple approach can work best.
- It is fast and simple: the runtime depends on the Laplacian pyramid construction and image resolution.
  - 1.8 and 6.7 seconds for single scale.
  - 3.2 and 10.8 seconds for 4 pyramid levels.
  - Humming bird video took 0.96 seconds per frame.

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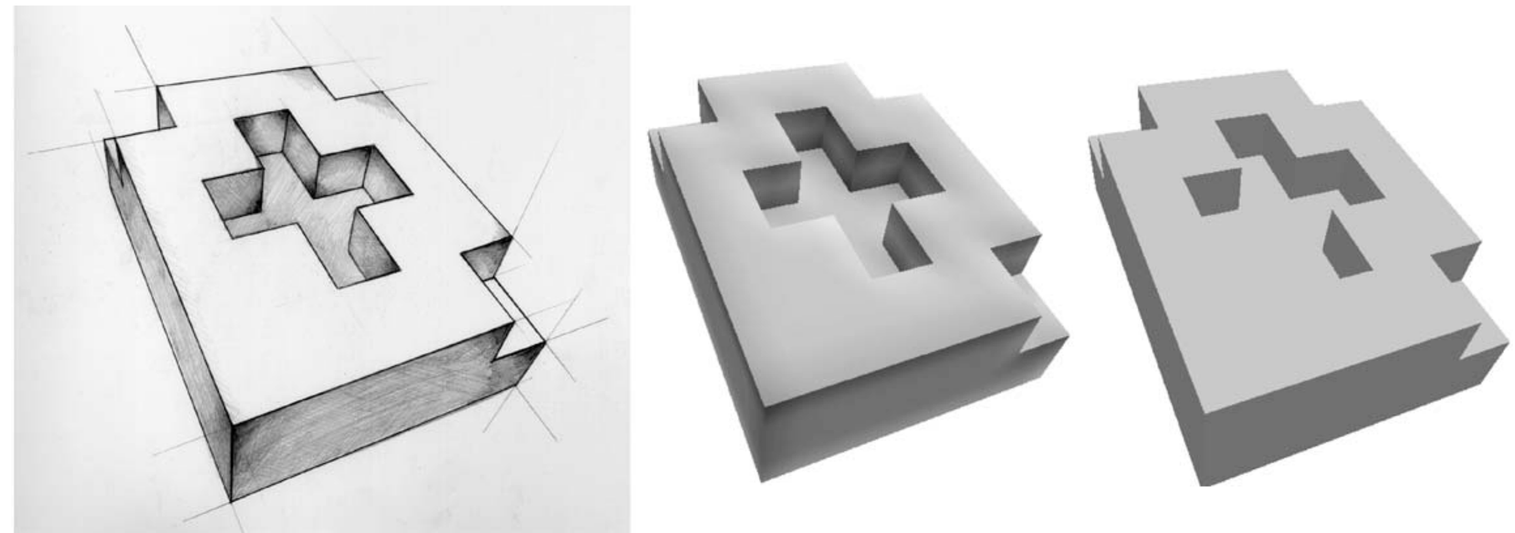
  - 3.2 and 10.8 seconds for 4 pyramid levels.
  - Humming bird video took 0.96 seconds per frame.
- More sophisticated colour appearance prediction.
- Treat temporal coherence of local enhancement.
- Automatically control over-shot enhancements.

3D Unsharp Masking

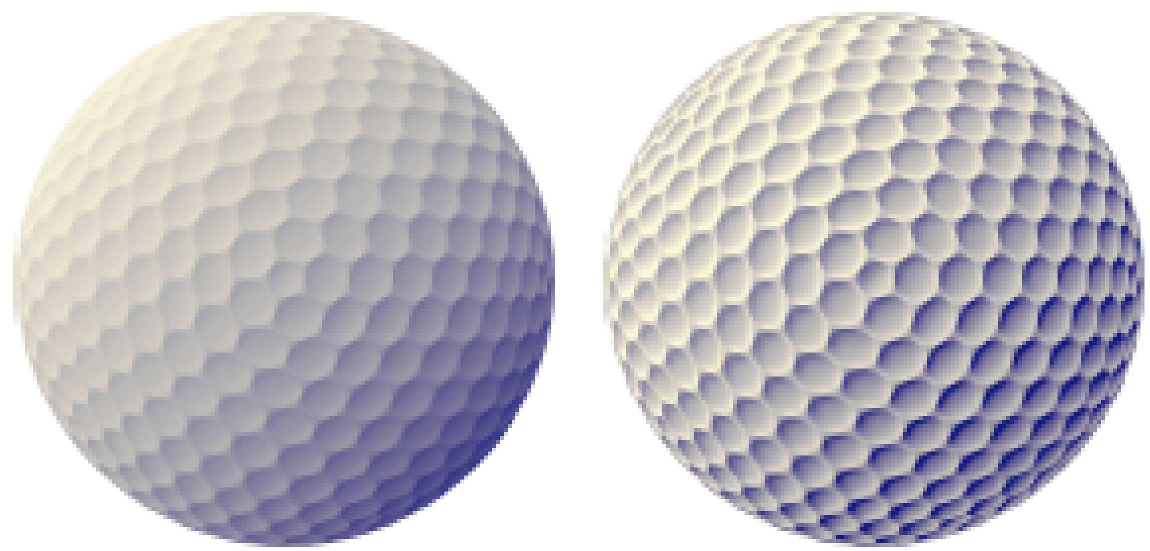
Scene Coherent Enhanced 3D Rendering

Related Work

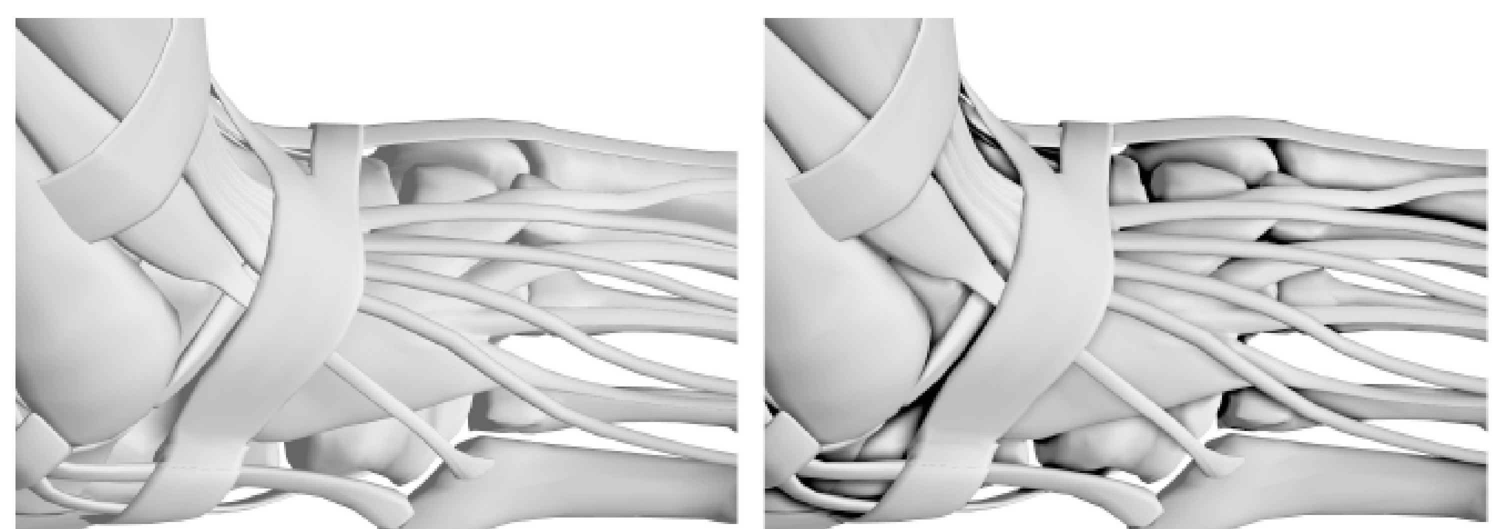
Normals Enhancement
Cignoni et al. C&G 2005



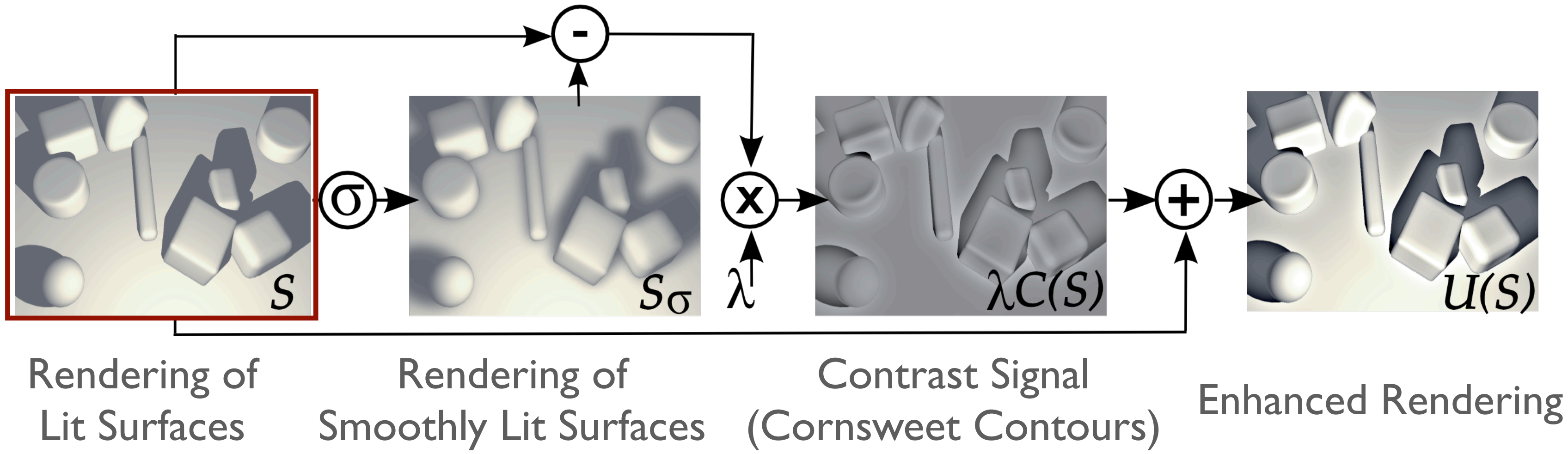
Exaggerated Shading
Rusinkiewicz et al. SIGGRAPH 2006



Unsharp Masking the Depth Buffer
Luft et al. SIGGRAPH 2006

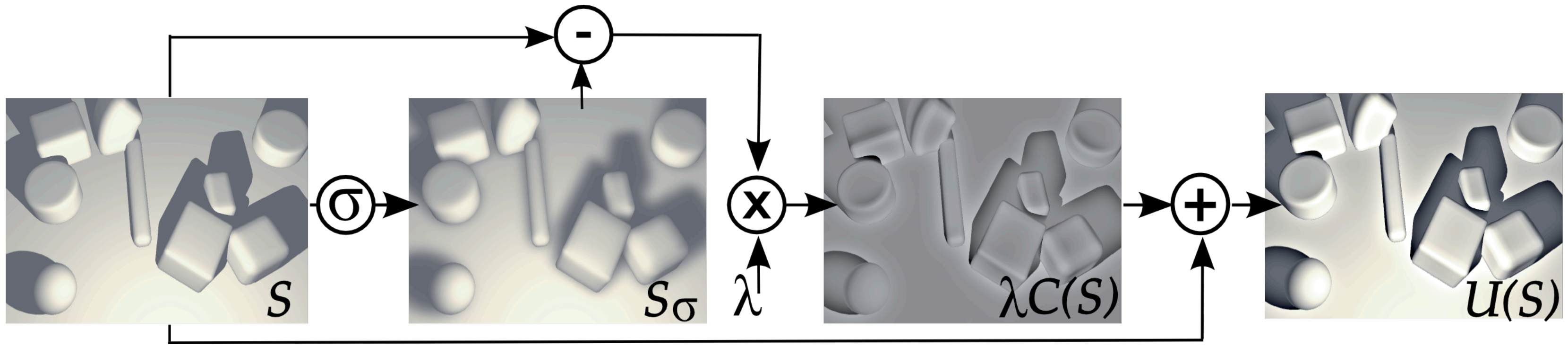


3D Unsharp Masking



Lit 3D Surface

3D Unsharp Masking

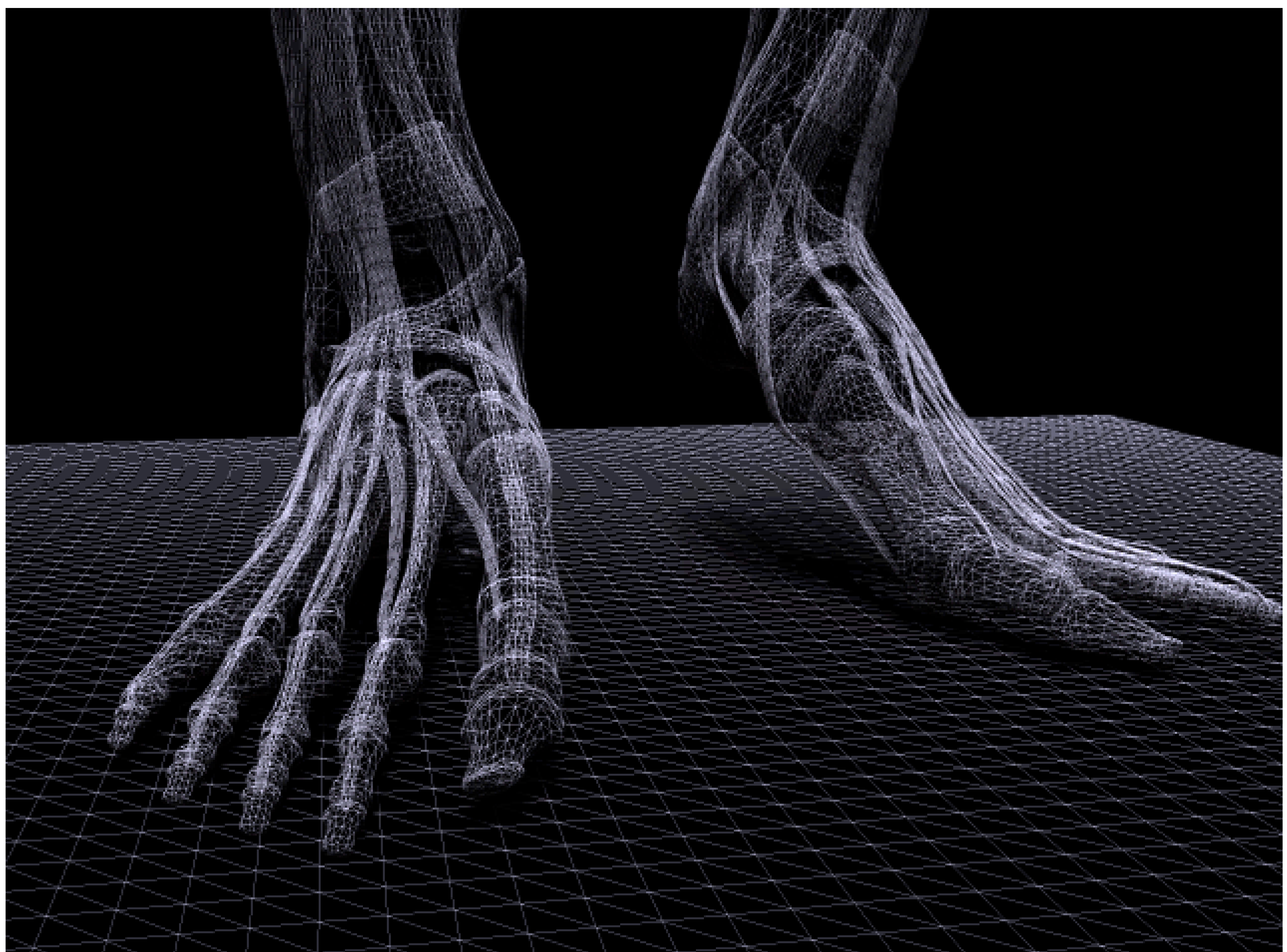


Rendering of Lit Surfaces

Rendering of Smoothly Lit Surfaces

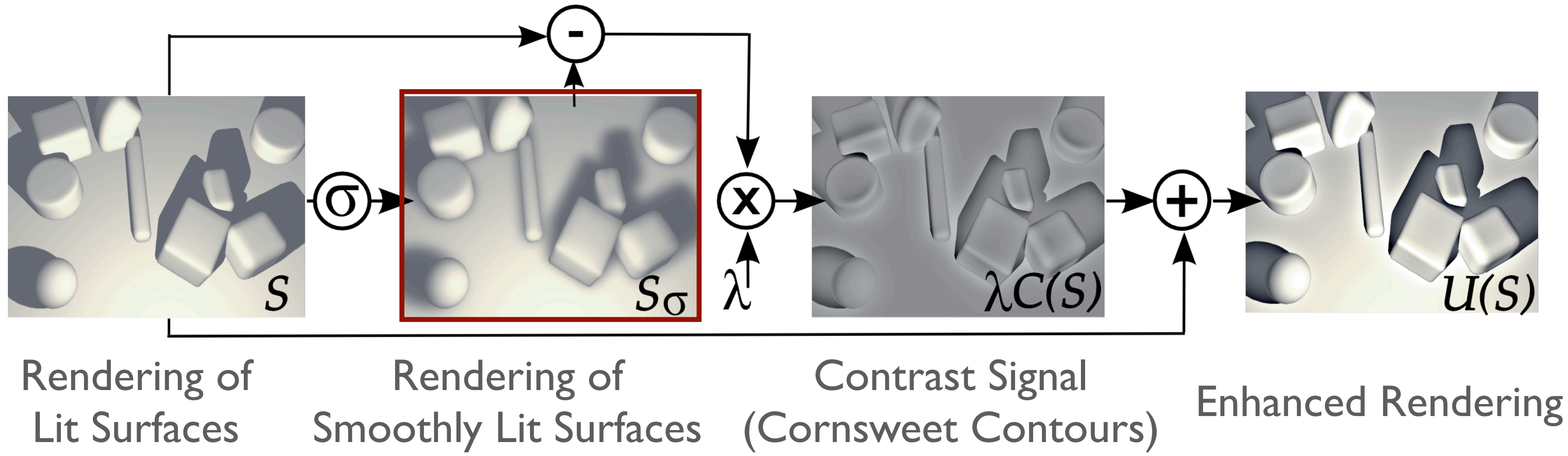
Contrast Signal (Cornsweet Contours)

Enhanced Rendering



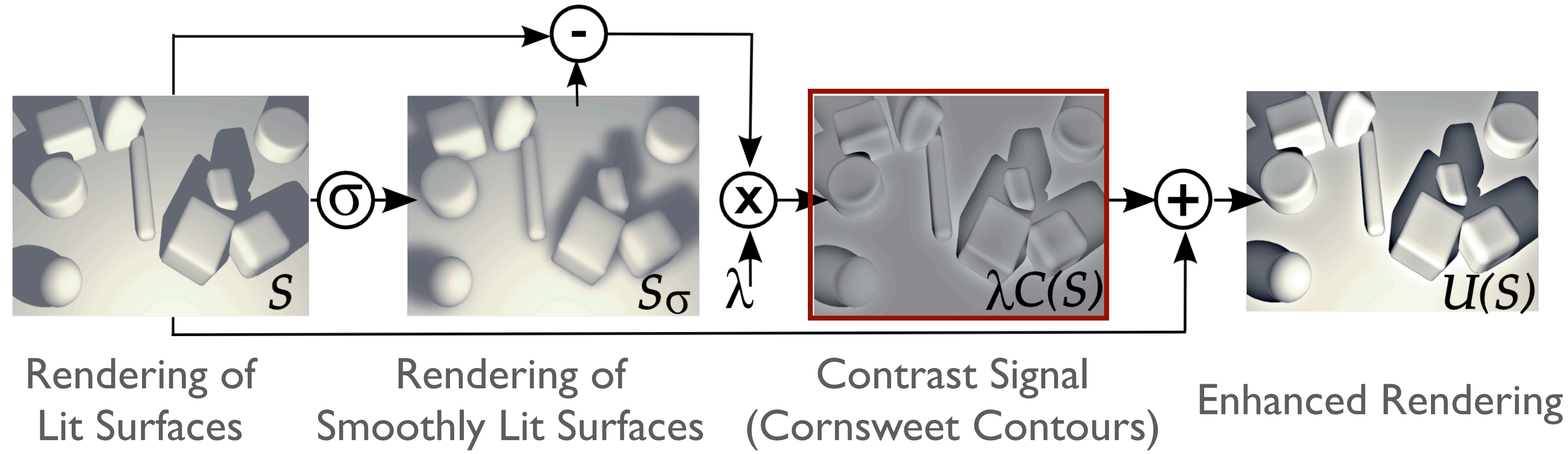
3D Surface

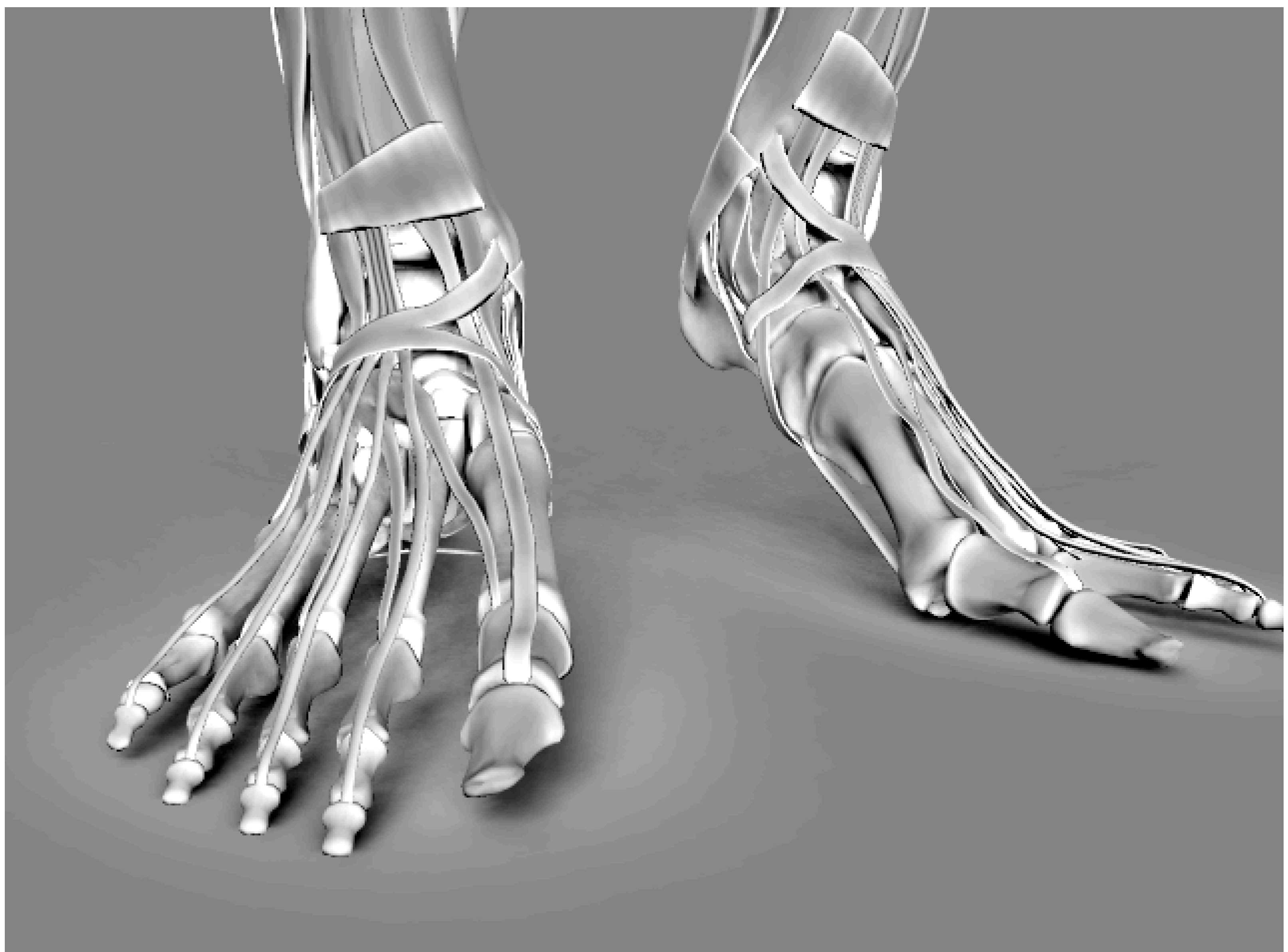
3D Unsharp Masking



Smoothly Lit 3D Surface

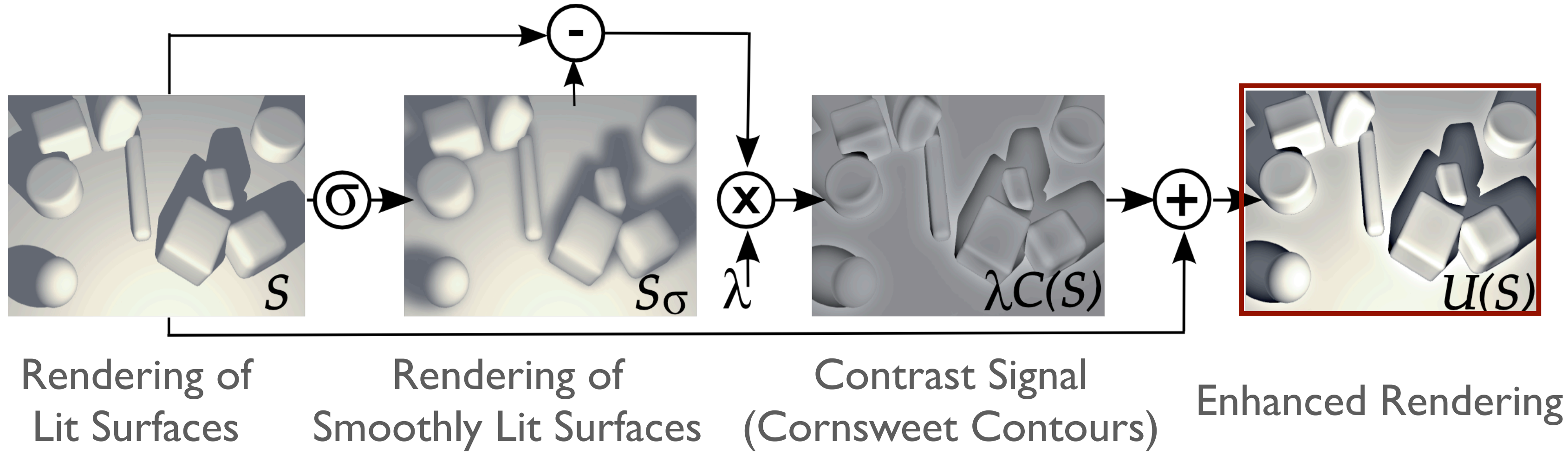
3D Unsharp Masking





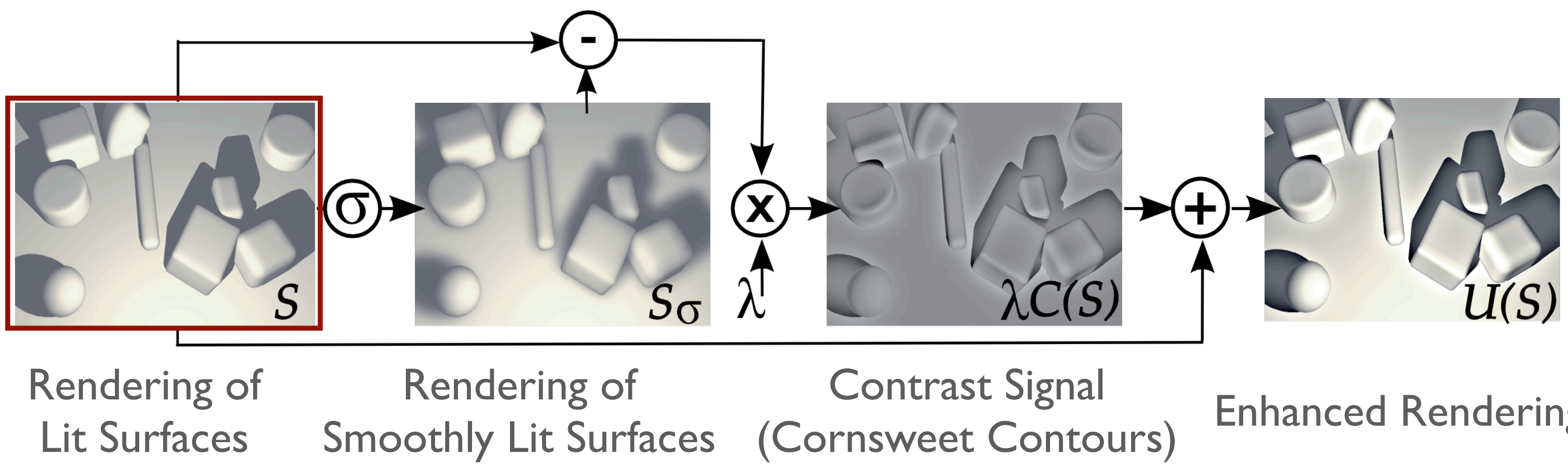
Scene Coherent Contrast Signal

3D Unsharp Masking



Enhanced Rendering

3D Unsharp Masking



Original Rendering

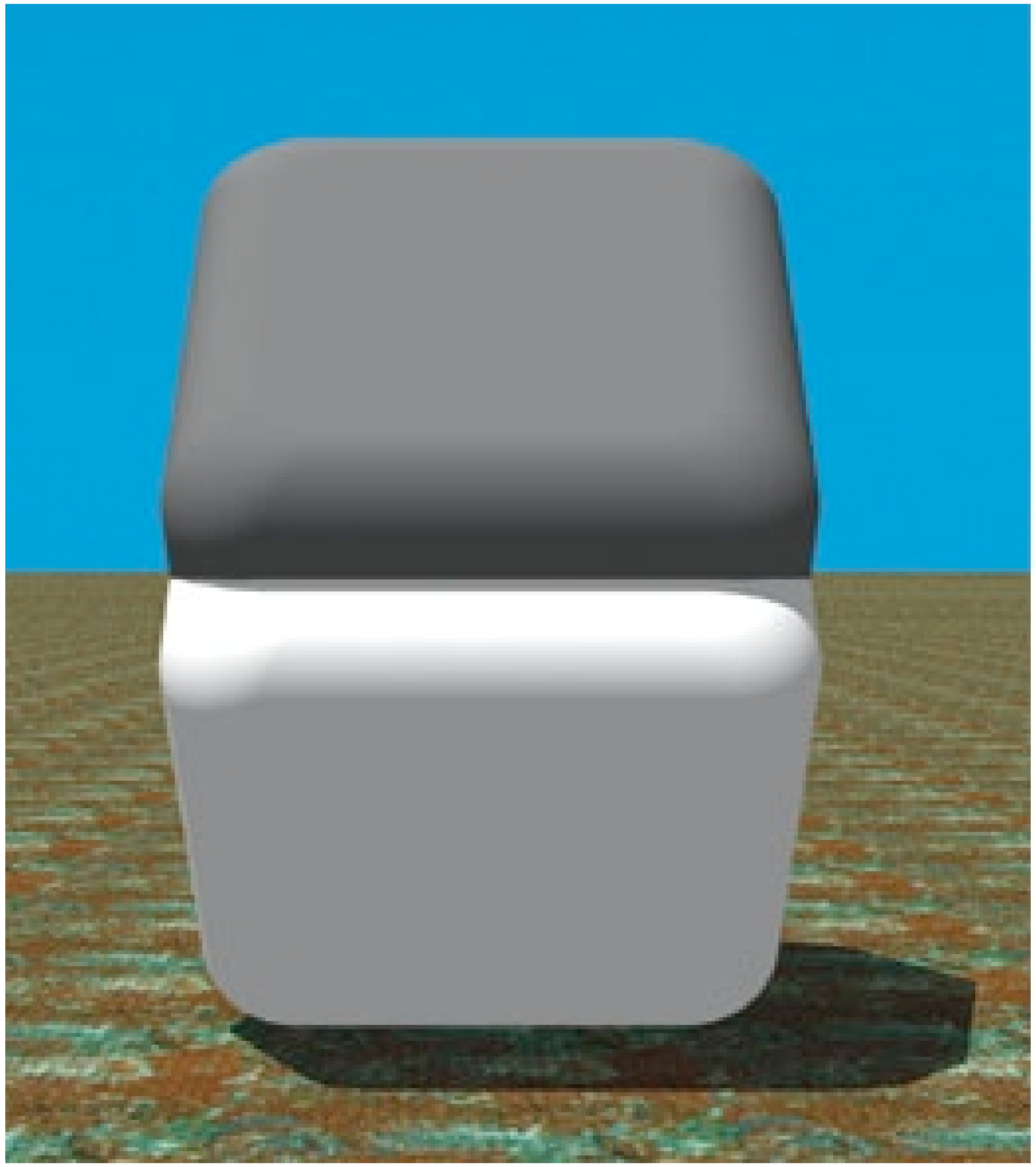
Complex Geometry

Basic Rendering

3D Unsharp Masking

3D Cornsweet Illusion

The effect of a Cornsweet contour is much stronger when it is enforced by 3D cues.



Dale Purves et al., 1999

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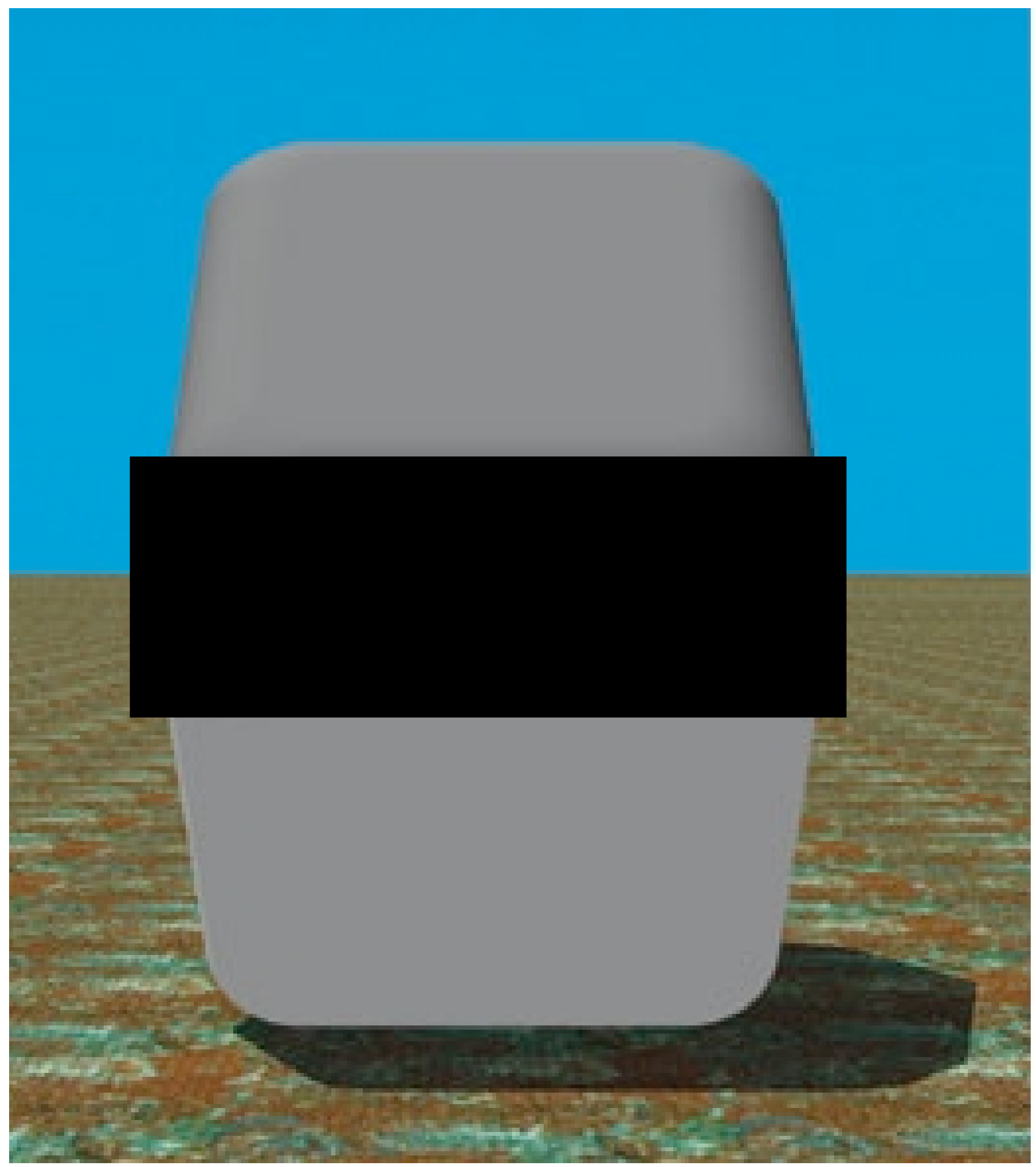
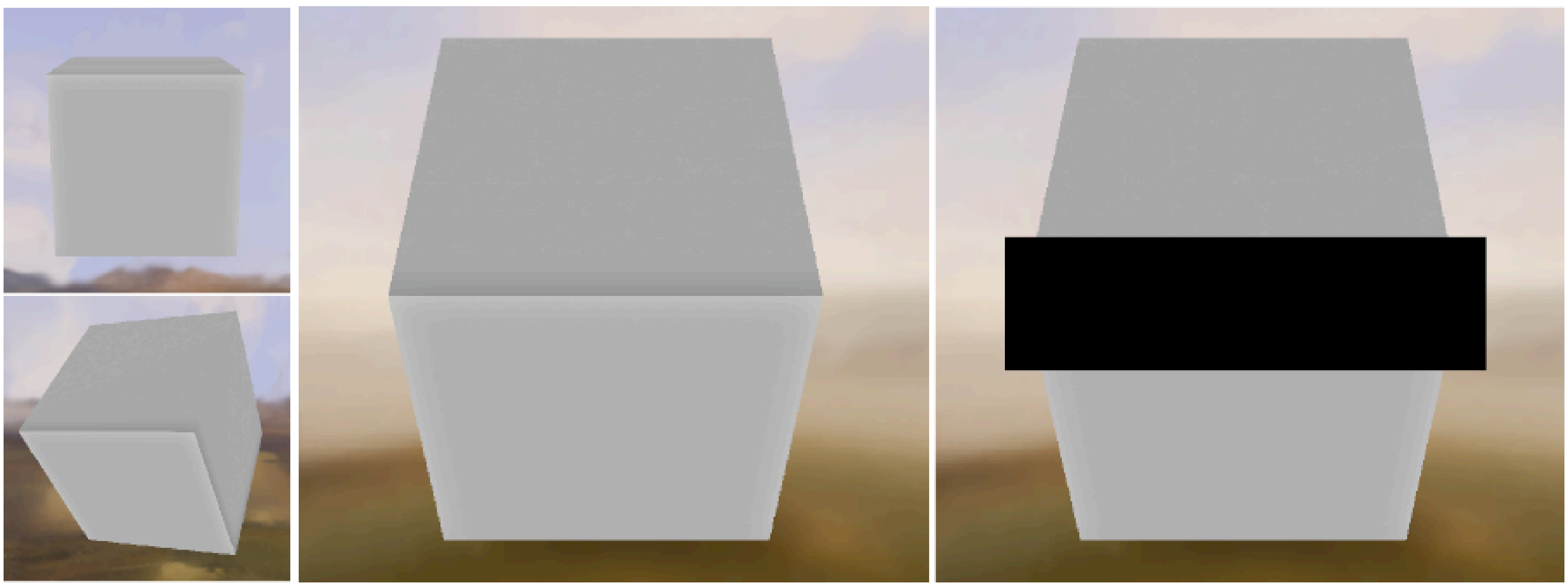
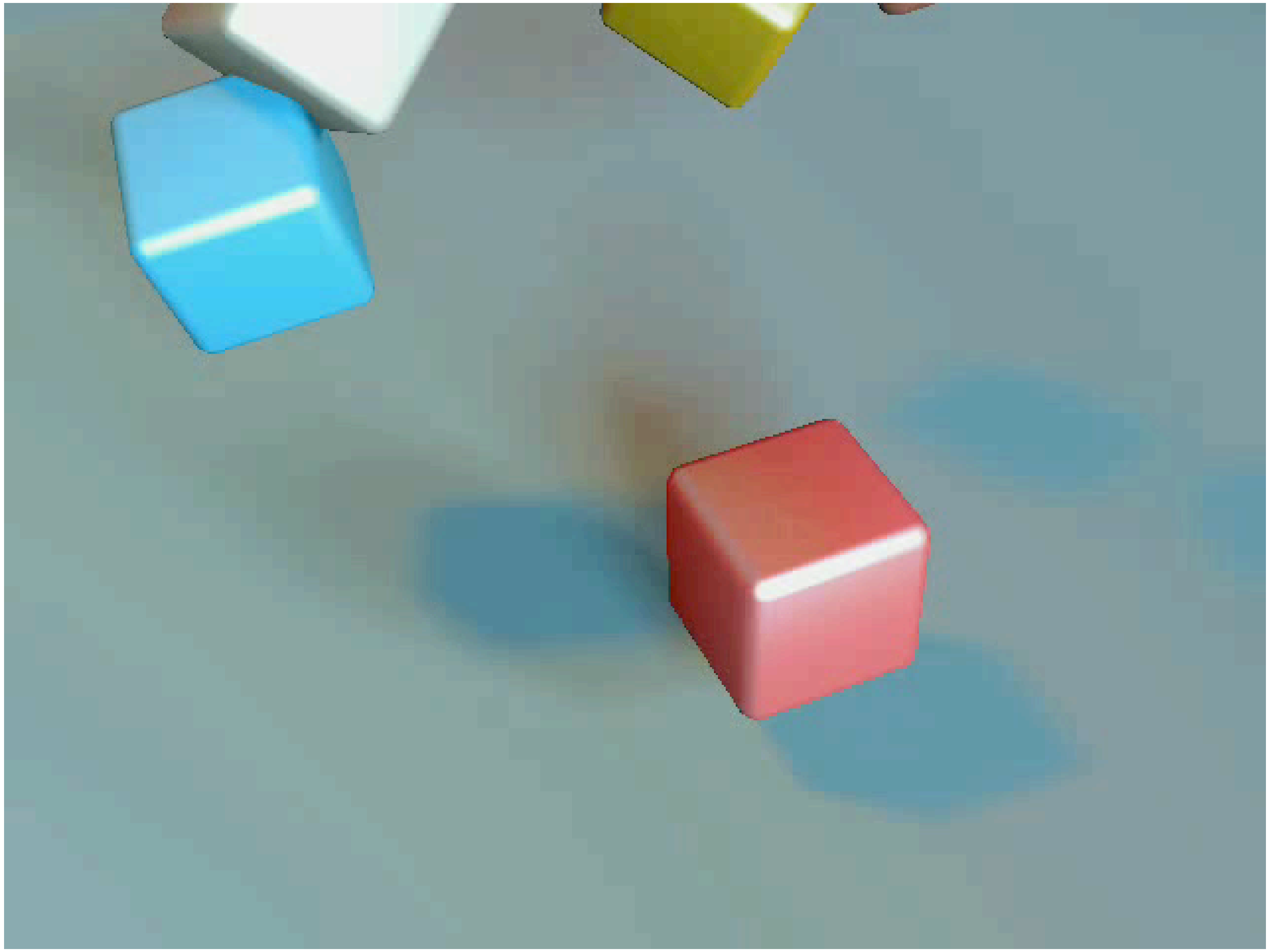


Dale Purves et al., 1999

Creating the 3D Cornsweet Illusion



Video Results



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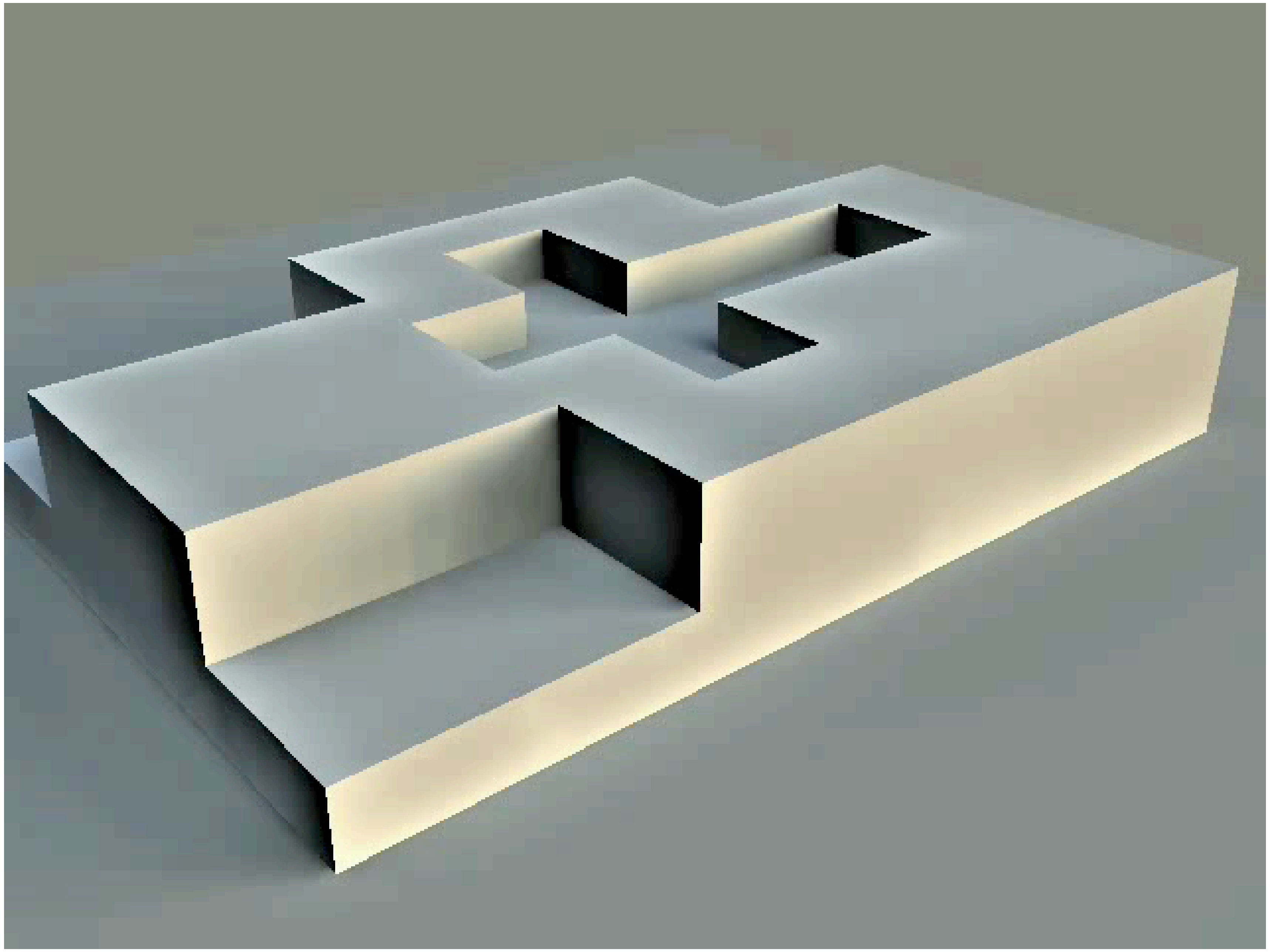
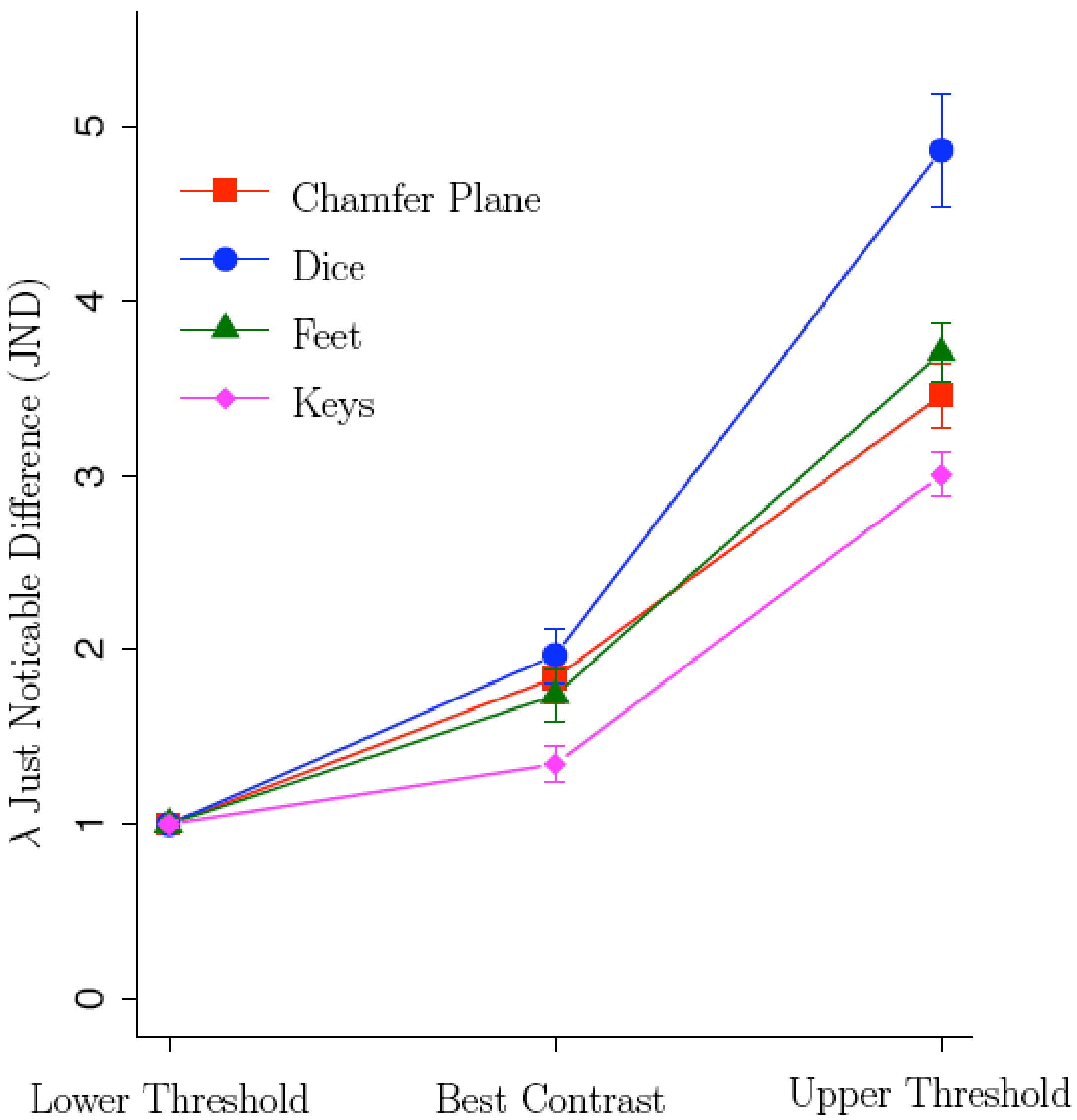
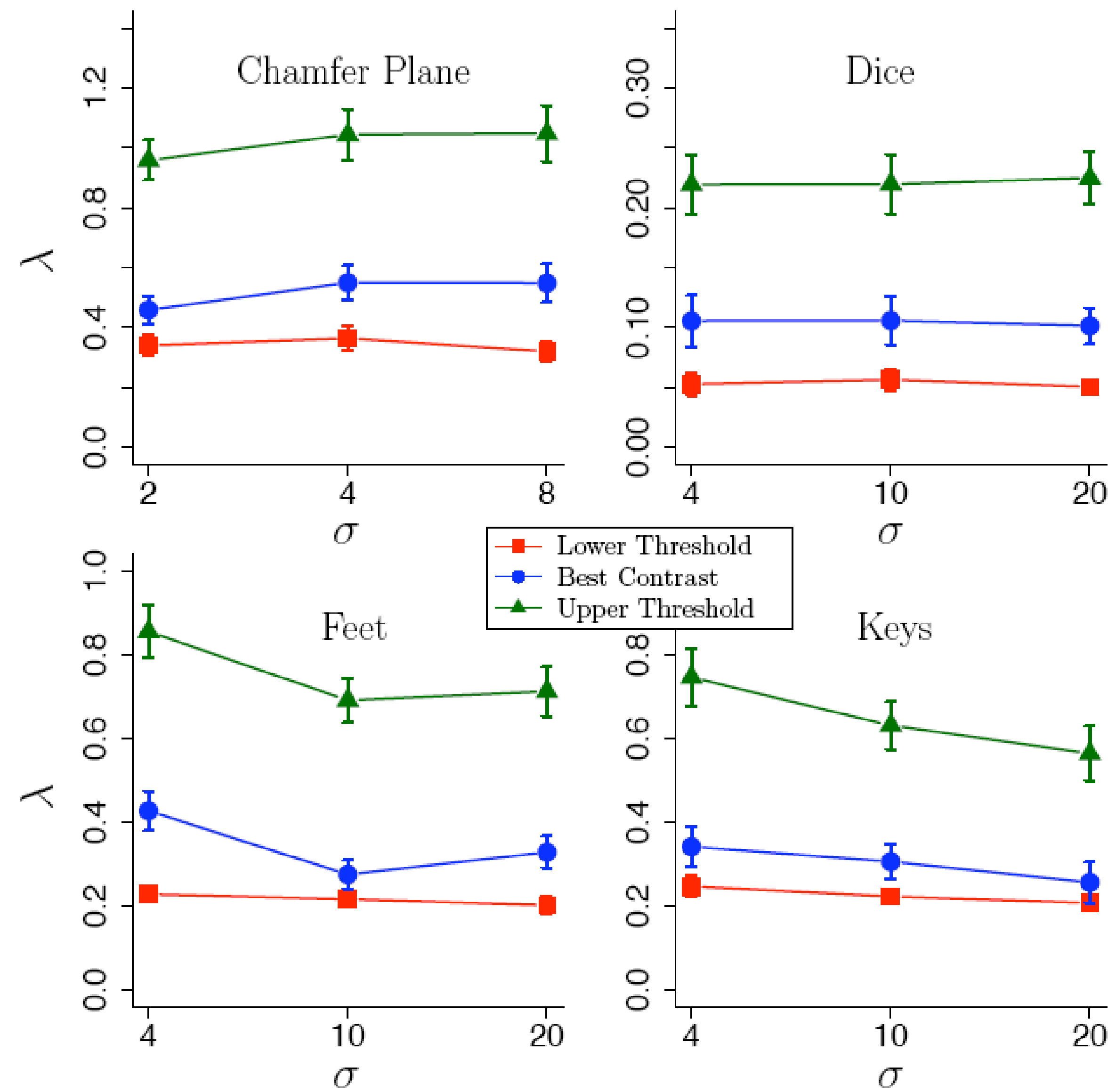


Perceived Effect

- Users prefer scenes enhanced by twice the just noticeable difference.
- Users tolerate up to four times just noticeable difference.
- Smoothing parameter σ has only a small effect.





Conclusions and Wish List

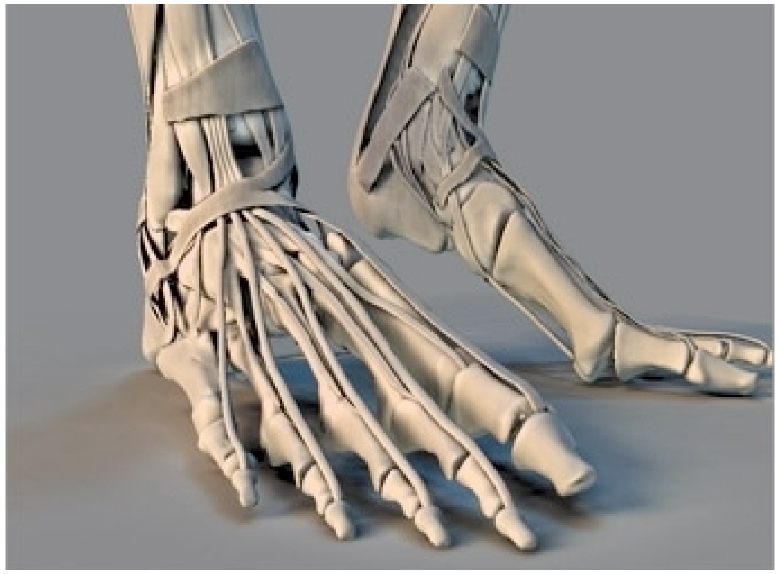
- Enhances all lighting gradients holistically.
- Improves over existing approaches, is more flexible and robust.
- Investigate temporal coherence of 3D unsharp masking of defoming meshes with topology changes.
- Extend to multi-scale allowing smoothing parameter to adapt over the scene.

Final Conclusions

- Depiction of contrast despite constraints.
- Champions the use of perceptual models and visual effects in computer graphics algorithms.
- Foundations in the human visual system and perception results in algorithms that create more effective imagery.

Beyond Tone Mapping

Apparent Greyscale



3D Unsharp Masking

Acknowledgements

- Collaborators - Pierre-Edouard Landes, Joelle Thollot, Karol Myszkowski, Tobias Ritschel, Matthias Ihrke, Thorsten Grosch.
- Sabine Budde - for saving me from self-created bureaucratic nightmares.
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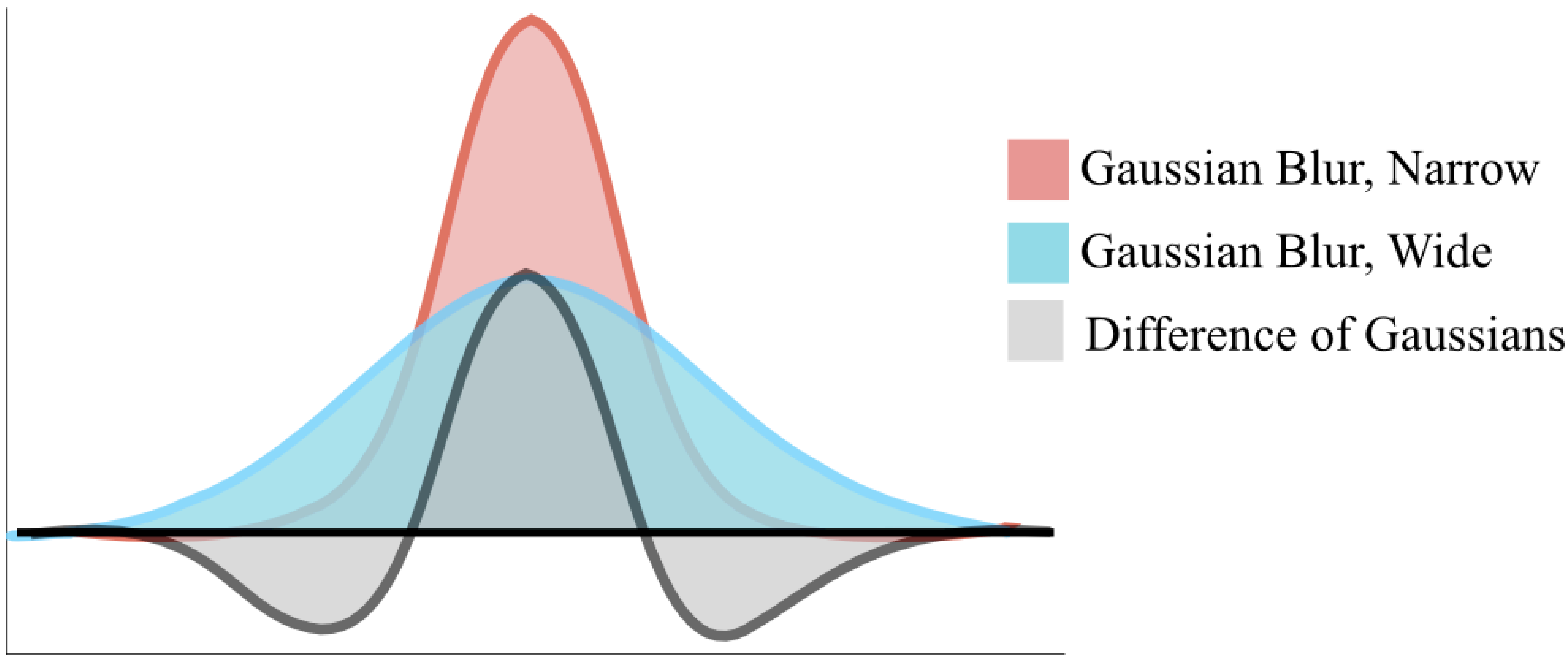
- Danielle, Amy (for her greyscale support), Nina, Louigi, Paul.
- Germany friends - Bernd, Stefan, Olli, Uschi and Stefan, Brice, Simone, Dagmar.
- MPI D4 group for CG lunches and daytime banter.
- INRIA ARTIS group for LRP brownie sharing and research inspiration.
- George Drettakis, Oliver Deussen, Allison Klein, Victor Ostromoukhov.

Additional Slides
(To Answer Anticipated Questions)

Difference of Gaussians (DoG)

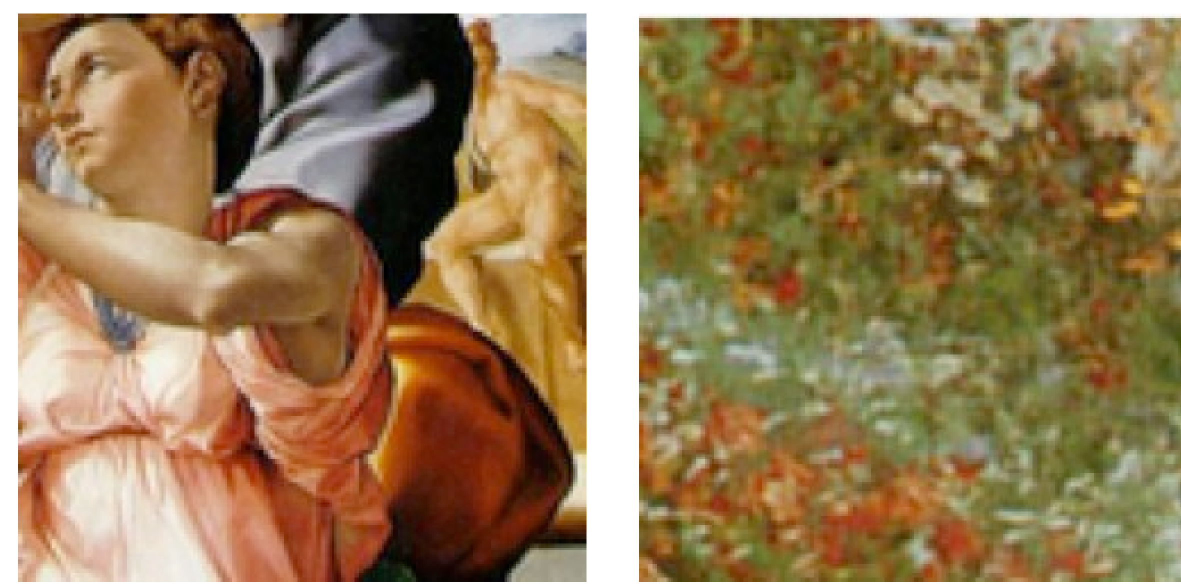
- Center-Surround cellular processing.
- Approximates 2nd derivative, Laplacian.



Restore Contrast with Colours

- Restore the lost luminance contrast by introducing colour contrasts.
- Create enhanced images with more loyal luminance range or details visibility.
    - Colours don't interfere with user-chosen luminance.
    - Colours create strong effects.
    - Colours integral to art and effective techniques known.

Increases Global Contrast Appearance



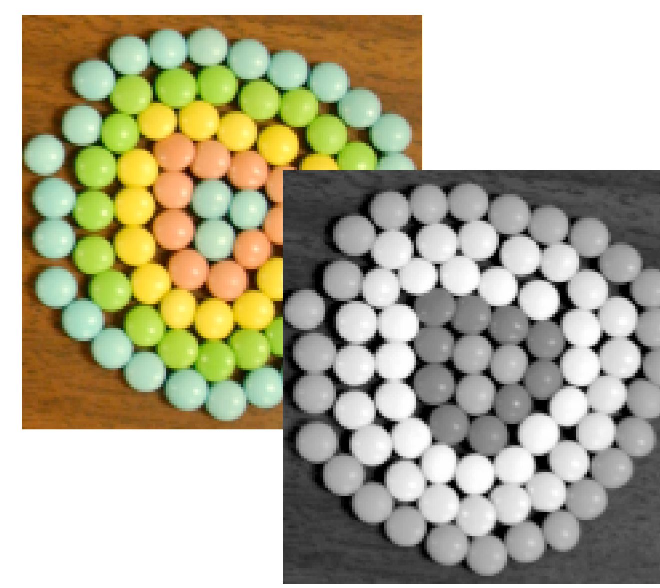
Increases Details Salience

Recent Greyscale Methods

Techniques to maintain discriminability use optimization, poisson solution, custom colour spaces.

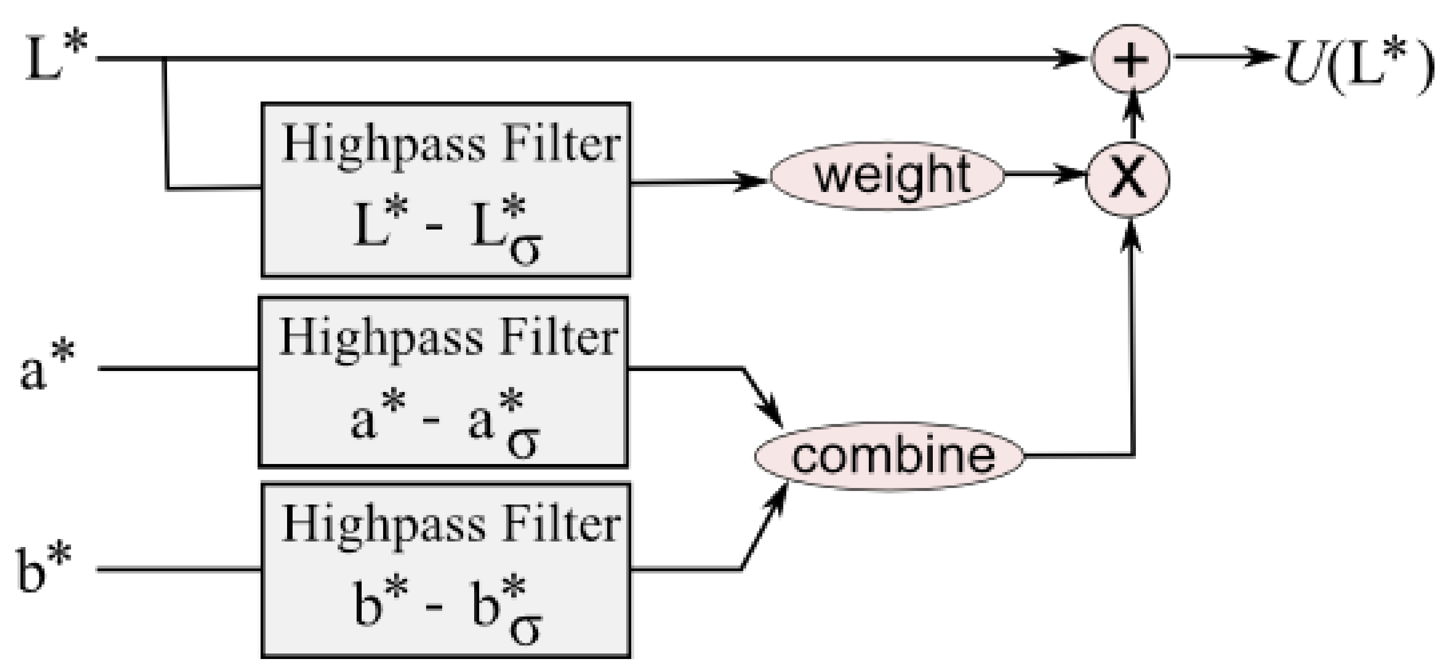
- Color2Gray: salience-preserving color removal [Gooch et al., Siggraph 2005]
- Recoloring images for gamuts of lower dimension [Rasche et al., Eurographics 2005]
- Fast, contrast enhancing, color to grayscale conversion [Grundland et al., Pattern Recogn. 2007]
- An efficent perception-based adaptive color to gray transformation [Neumann et al., Comp. Aesthetics 2007]

Gooch C2G


Rasche

Recent Greyscale Methods

- Color-to-grayscale conversion to maintain discriminibility [Bala et al., SPIE 2004]
- Spatial color-to-grayscale transformation preserving chrominance edge information [Bala et al., Color Imaging Conference 2004]



Impression Sunrise

Original

Gooch et al. Color2Gray

Impression Sunrise

Original

Neumann et al.

The Helmholtz-Kohlrausch Effect

"A chromatic stimulus with the same luminance as a white reference stimulus will appear brighter than the reference."

- Y. Nayatani

Two experimental approaches for measuring this effect:

- **VCC** (variable-chromatic-colour) - subjects adjust a colour's chromaticity until its brightness matches a grey stimulus.
- **VAC** (variable-achromatic-colour) subjects match grey values to given colour stimulus.

Adaptive Gain Factor

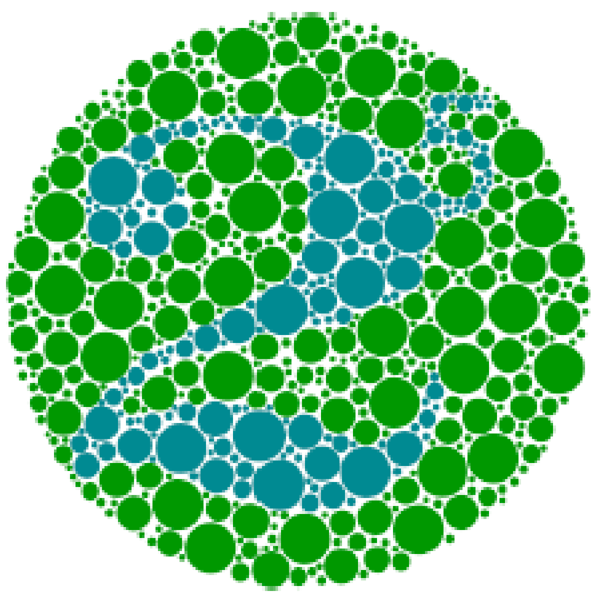
- Measures the chromatic contrast to be restored.
- Ratio of original and greyscale contrast measured in CIELAB ΔE perceptual colour differences.

$$\lambda_i = \left(\frac{\Delta E(h_i(I))}{|h_i(G_{L^*})|} \right)^p$$

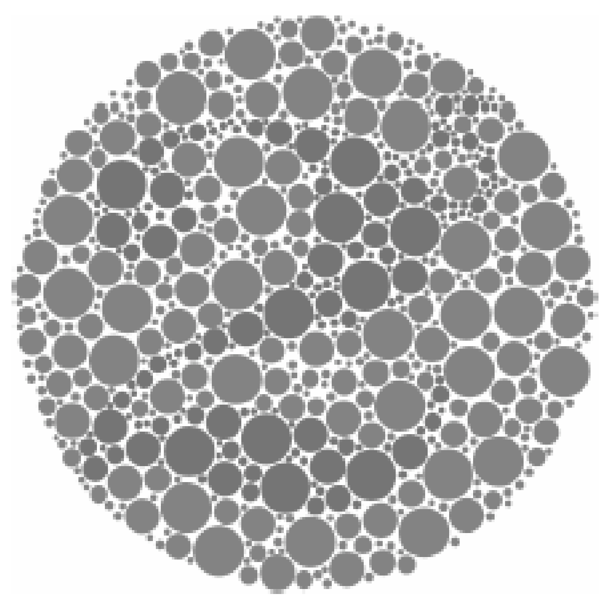
- $h_i(I)$ is contrast because it is the difference between a pixel and its neighbourhood.
- $\Delta E(h_i(I))$ is the Euclidean distance in LAB.
- $|h_i(G_{L^*})| \sim \Delta E(h_i(G))$ because the chromatic channels of G contain no contrast information.

Limitations of Our Work

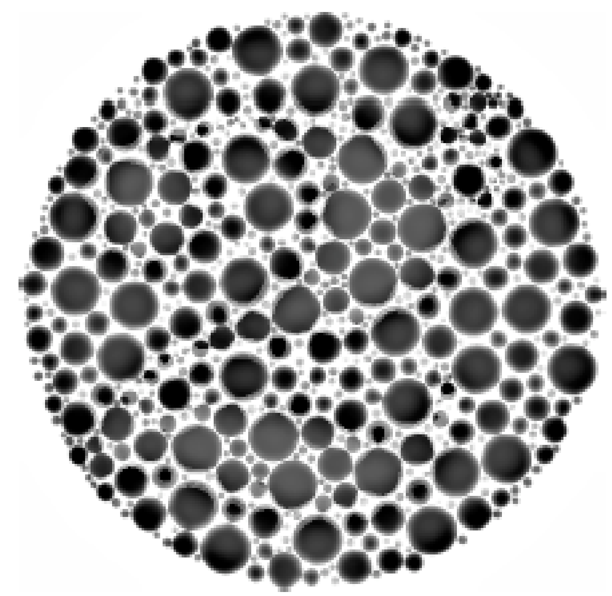
- Chromatic contrast adjustment is local: it cannot enhance contrast between non-adjacent regions.



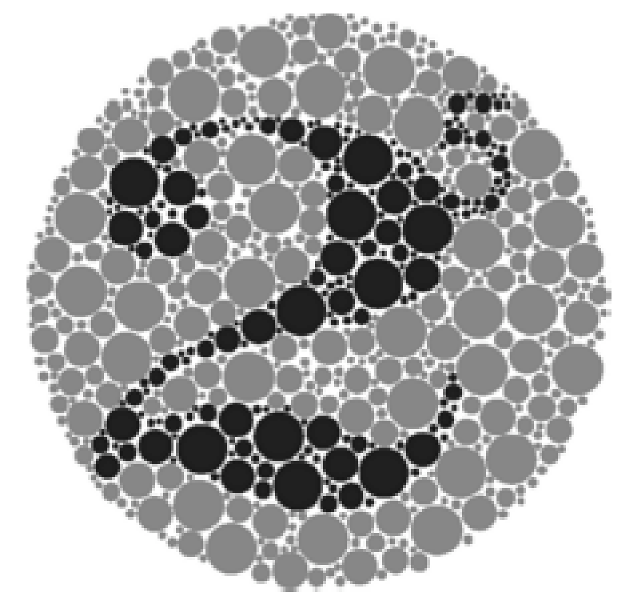
Original



Globally Mapped G



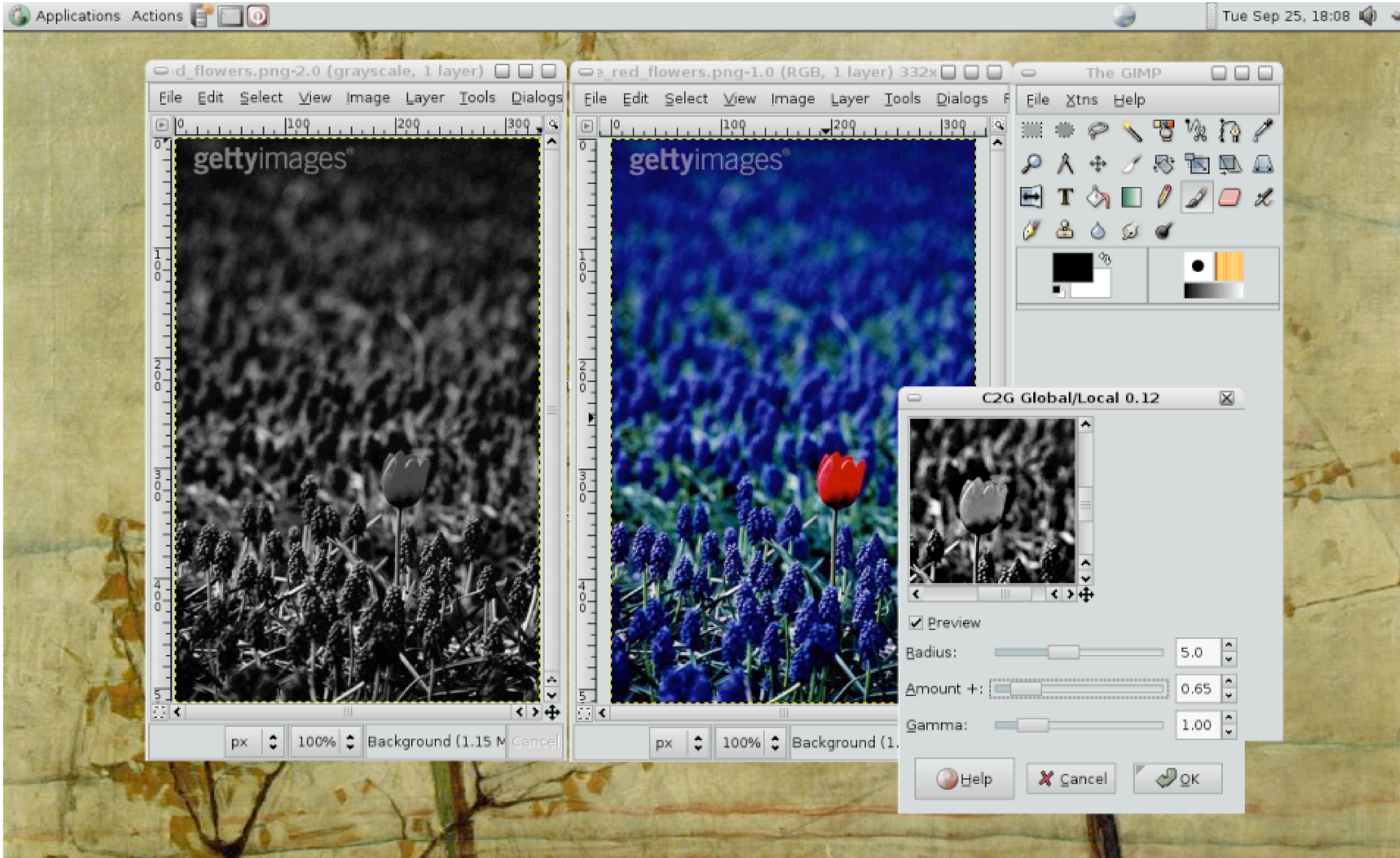
Apparent Greyscale



Histogram Equalization of Globally Mapped G

- Local enhancement is done frame-by-frame - may produce temporal incoherence; but in the examples we tried, this is not a problem [see video results].

Apparent Greyscale Plug-In



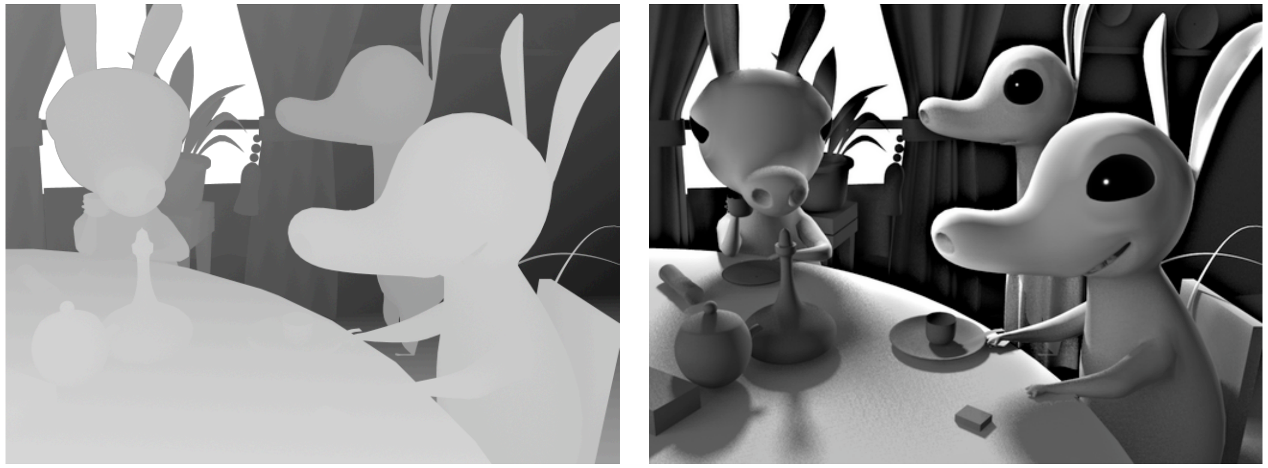
Effect of Smoothness Parameter σ

Original *S*

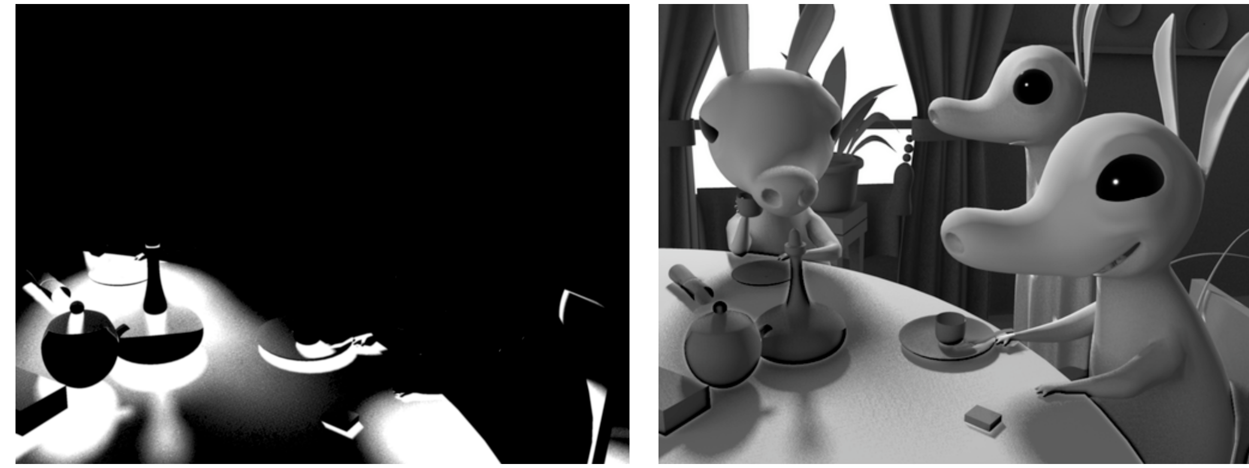
Unsharp *U(S)* $\sigma = 4$ $\lambda = 0.65$

Unsharp *U(S)* $\sigma = 20$ $\lambda = 0.65$

2D Buffer Unsharp vs. 3D Unsharp

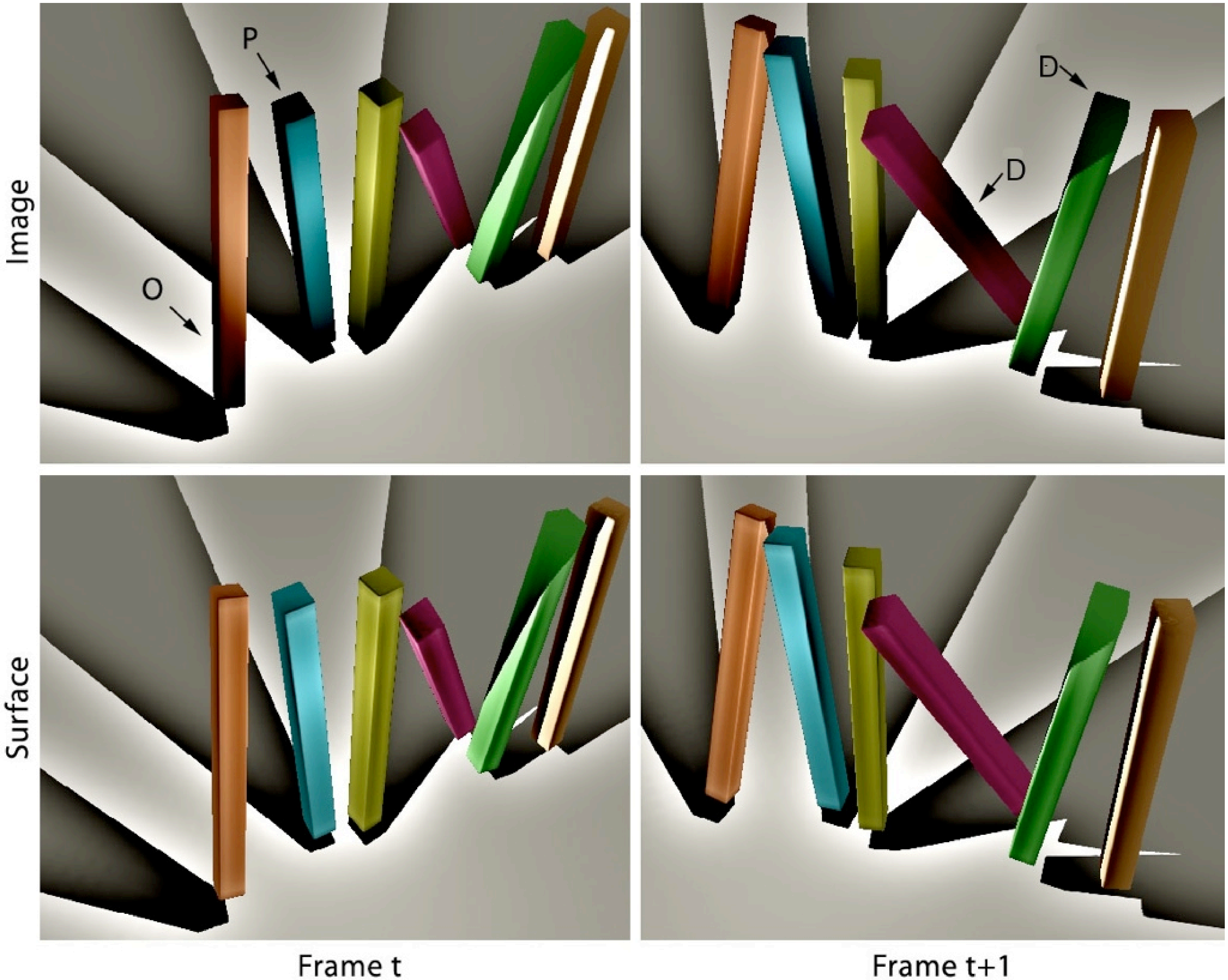


Depth Buffer Unsharp



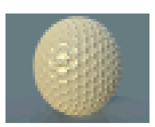
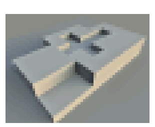
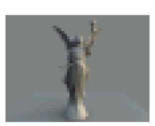
Shadow Buffer Unsharp

Comparison 2D to 3D



O - spurious occlusion enhancements D - distant objects affect eachother P - adapt to perspective

3D Unsharp Timing Numbers

	Scene	Lighting	FPS			Vertices	σ	Time		Supersampling	
			Total	W/Out	Extra			Light	Smooth	Surface	Framebuffer
	Feet	Natural	10.2	15.2	33 %	57 k	5	26.5	3.7	no	none
	Dice	Point	15.6	63.0	75 %	74 k	1	1.7	4.9	yes	2×2
	Keys	Point	15.2	63.0	76 %	152 k	20	5.1	34.0	no	2×2
	Columns	Point, AO	28.3	63.2	55 %	119 k	2	7.5	2.5	no	2×2
	Chamfer	Natural	8.3	10.7	22 %	39 k	2	20.0	10.1	no	none
	Golfball	Natural	17.9	31.3	43 %	127 k	8	14.3	10.3	no	none
	Cross	Natural	10.9	12.4	16 %	8 k	10	7.2	4.7	no	none
	Lucy	Natural	9.5	37.5	75 %	262 k	40	16.3	62.2	no	none

Mesh Dependence