Computational Photography

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Spring 2022

http://www.cs.pdx.edu/~fliu/courses/cs510/

04/12/2022

Last Time

- Filters
- De-noise

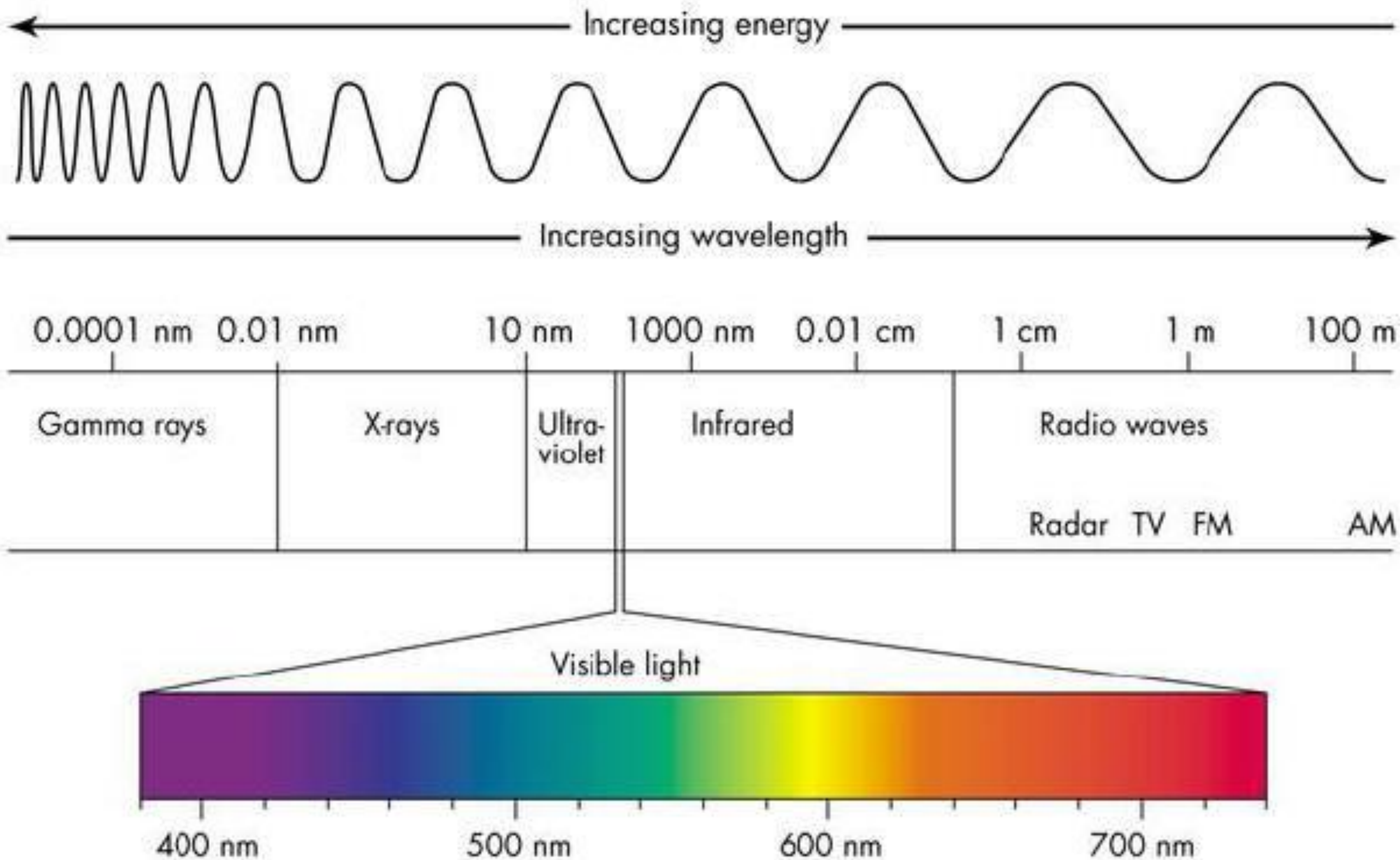
Today

- Color
- Color to Gray

Light and Color

- The frequency of light determines its “color”
  - Wavelength is related
  - Energy also related
- We care about wavelengths in the visible spectrum: between the infra-red (700nm) and the ultra-violet (400nm)

Color and Wavelength

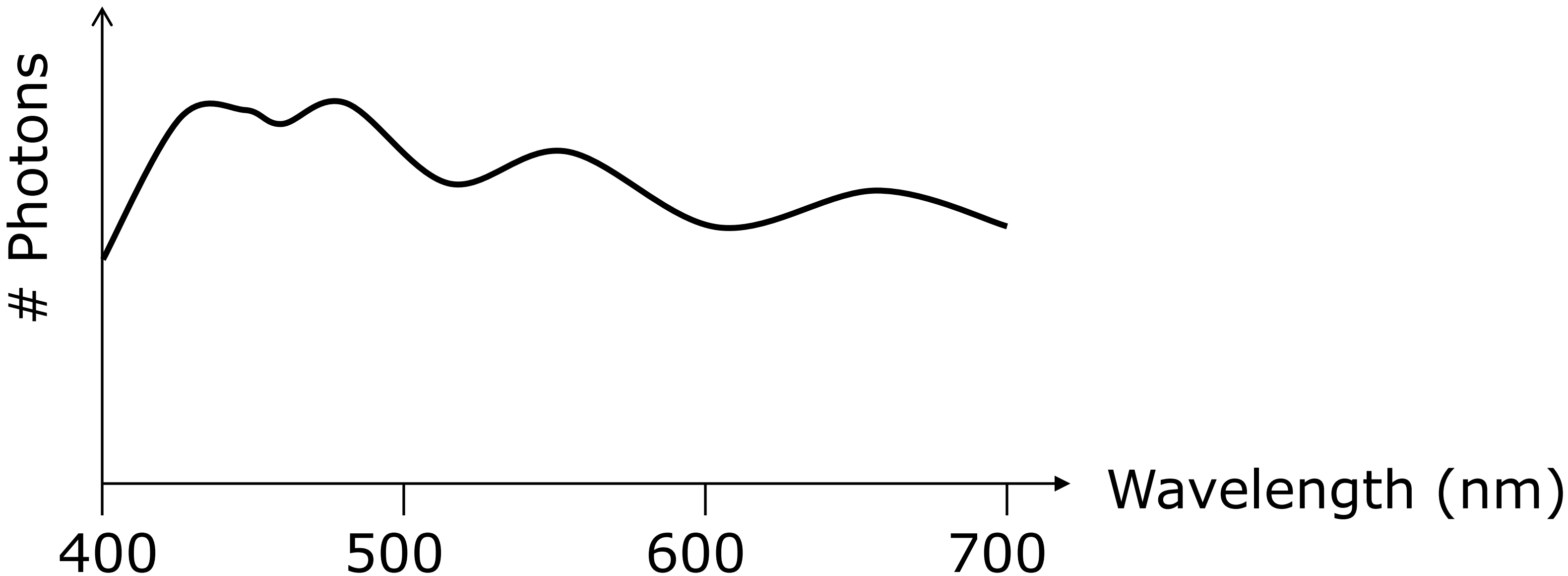


Light and Color

- The frequency of light determines its “color”
  - Wavelength is related
  - Energy also related
- We care about wavelengths in the visible spectrum: between the infra-red (700nm) and the ultra-violet (400nm)
- Describe incoming light by a *spectrum*
  - Intensity of light at each frequency
  - A graph of intensity vs. frequency

Normal Daylight

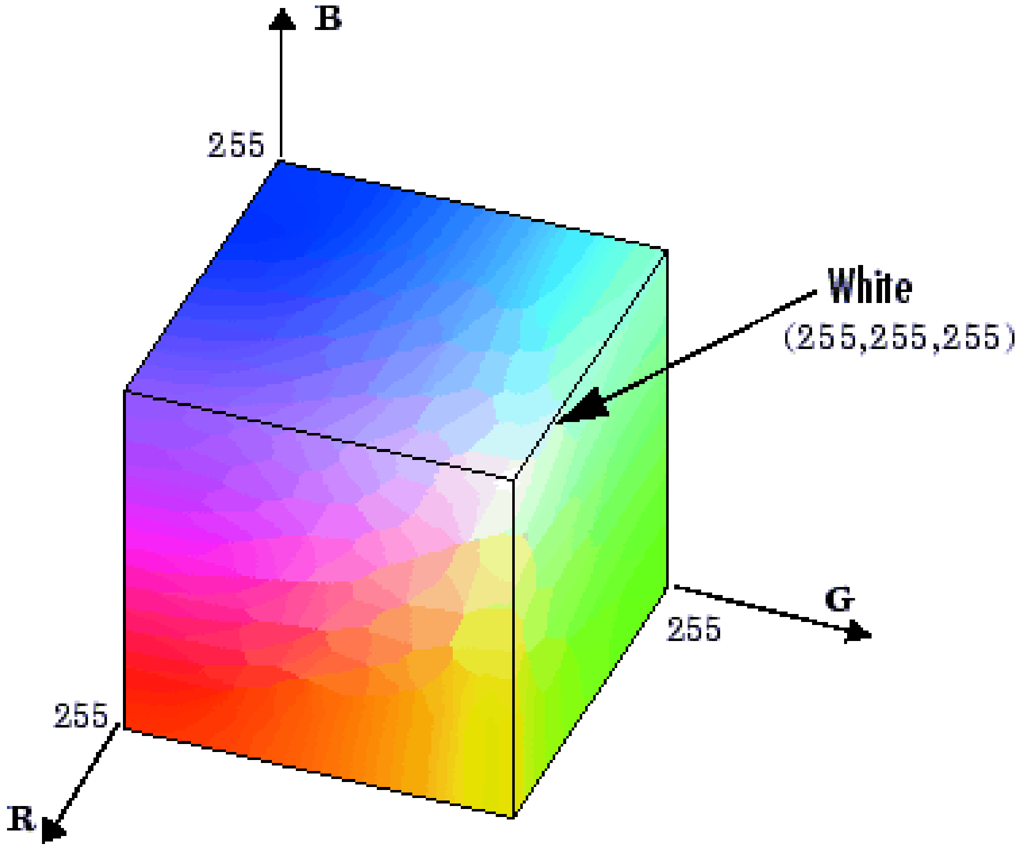
- Note the hump at short wavelengths - the sky is blue



Color Spaces

- The principle of trichromacy means that the colors displayable are all the linear combination of primaries
- Taking linear combinations of R, G and B defines the *RGB color space*
  - the range of perceptible colors generated by adding some part each of R, G and B
- If R, G and B correspond to a monitor's phosphors (monitor RGB), then the space is the range of colors displayable on the monitor

RGB Color Space



MacAdam Ellipses

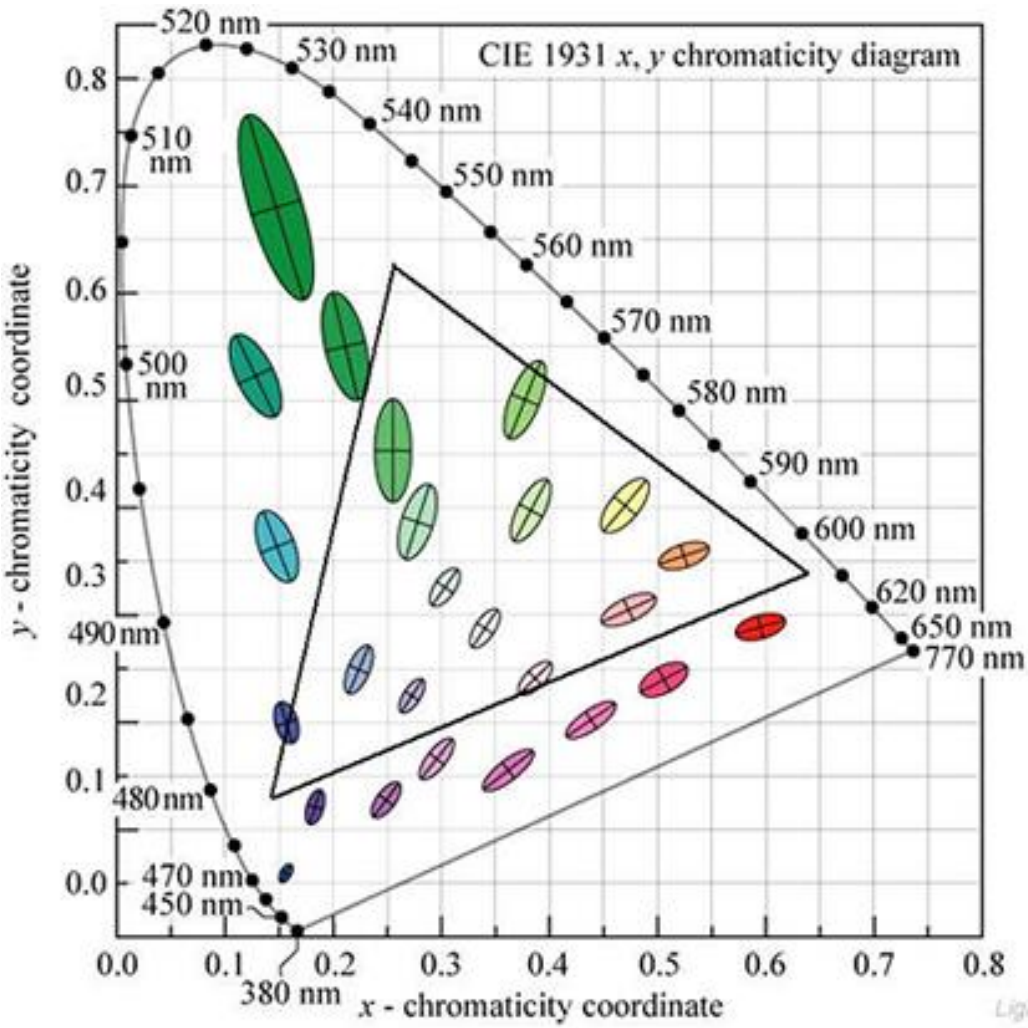


Fig. 17.5. MacAdam ellipses plotted in the CIE 1931 (x, y) chromaticity diagram. The axes of the ellipses are ten times their actual lengths (after MacAdam, 1943; Wright, 1943; MacAdam, 1993).

There is a general tendency in blues and purples for discrimination to be weaker in the yellow/blue direction than in the cyan/red direction (the ellipses are elongated in that direction); in greens discrimination is worse along a purple/green line; and in reds the discrimination is worse along a red/cyan line.

Gamut boundaries (triangle) of a typical LCD display are shown inside

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

L*a*b* Color Space

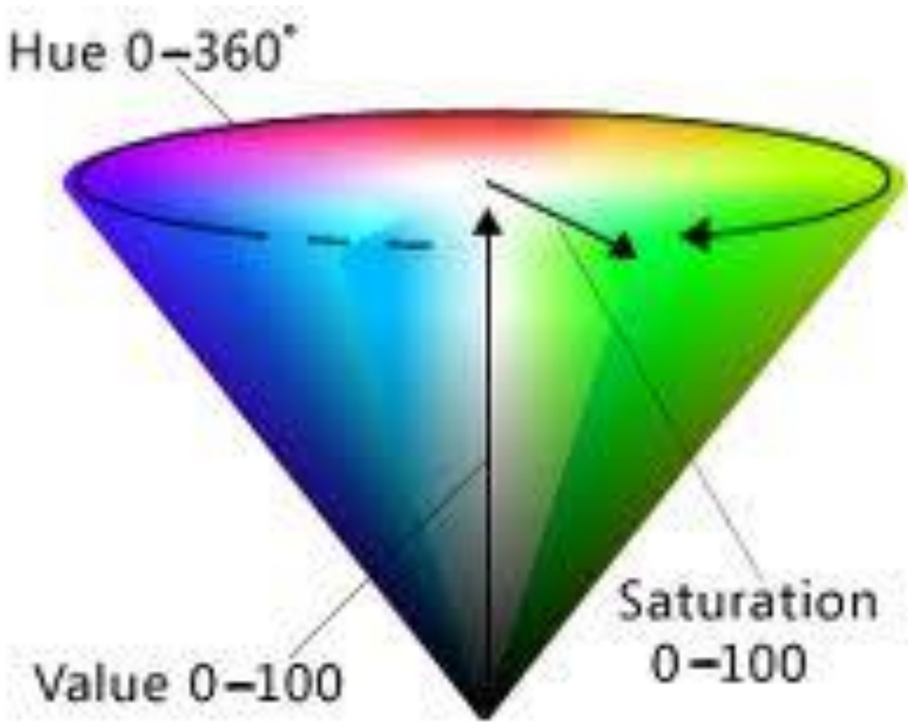
- RGB
  - Perceptually non-uniform
- L*a*b*
  - More perceptually uniform
  - Look into OpenCV for the conversion API

http://en.wikipedia.org/wiki/Lab_color_space

HSV Color Space (Alvy Ray Smith, 1978)

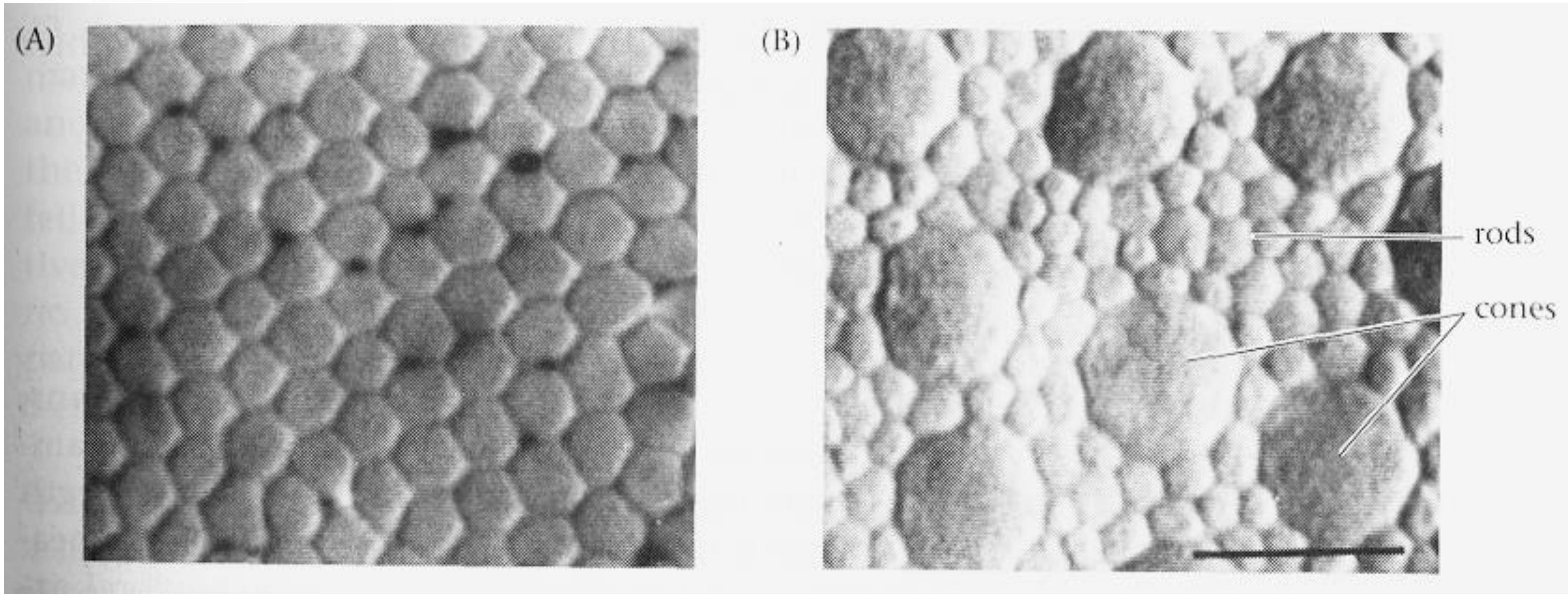
- Hue: the color family: red, yellow, blue…
- Saturation: The purity of a color: white is totally unsaturated
- Value: The intensity of a color: white is intense, black isn't
- Space looks like a cone
  - Parts of the cone can be mapped to RGB space
- Not a linear space, so no linear transform to take RGB to HSV
  - But there is an algorithmic transform

HSV Color Space



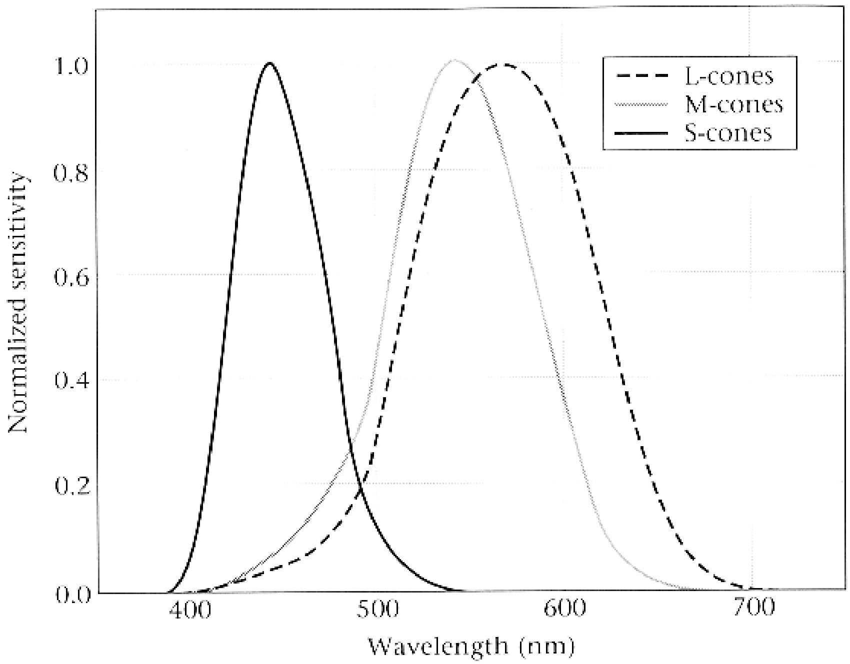
Seeing in Color

- The eye contains *rods* and *cones*
  - Rods work at low light levels and do not see color
    - That is, their response depends only on how many photons, not their wavelength
  - Cones come in three types (experimentally and genetically proven), each responds in a different way to frequency distributions



Color receptors

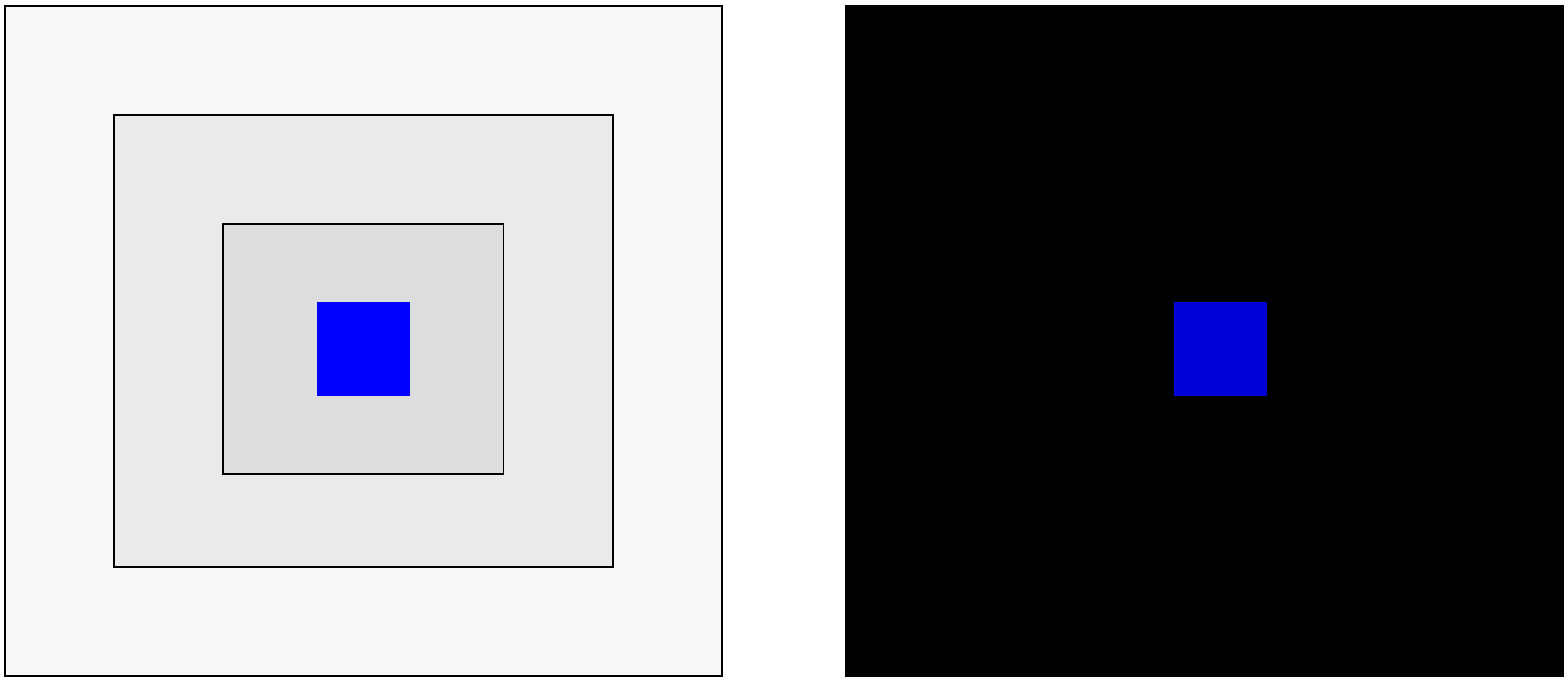
- Each cone type has a different sensitivity curve
  - Experimentally determined in a variety of ways
- For instance, the L-cone responds most strongly to red light
- "Response" in your eye means nerve cell firings
- How you interpret those firings is not so simple …



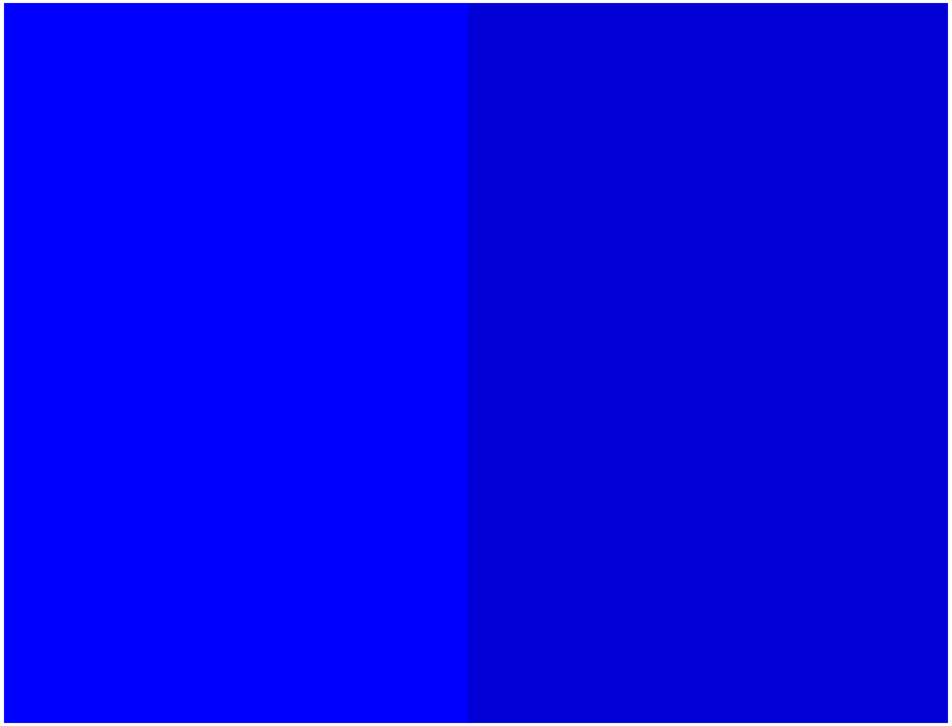
Color Perception

- How your brain interprets nerve impulses from your cones is an open area of study, and deeply mysterious
- Colors may be perceived differently:
  - Affected by other nearby colors
  - Affected by adaptation to previous views
  - Affected by "state of mind"
- Experiment:
  - Subject views a colored surface through a hole in a sheet, so that the color looks like a film in space
  - Investigator controls for nearby colors, and state of mind

The Same Color?



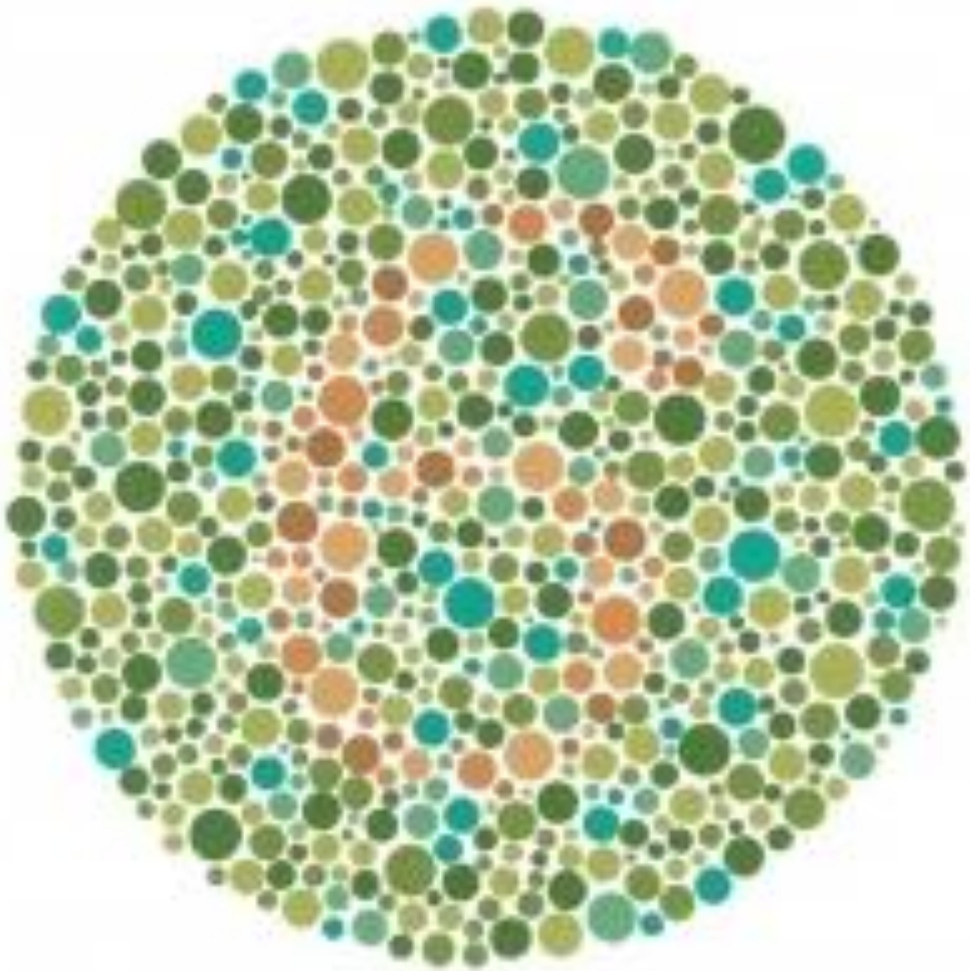
The Same Color?



Color Deficiency

- Some people are missing one type of receptor
  - Most common is red-green color blindness in men
  - Red and green receptor genes are carried on the X chromosome - most red-green color-blind men have two red genes or two green genes
- Other color deficiencies
  - Anomalous trichromacy, Achromatopsia, Macular degeneration
  - Deficiency can be caused by the central nervous system, by optical problems in the eye, injury, or by absent receptors

Color Deficiency



Color Transformation

- Re-coloring
- Color to Gray

Color2Gray:
Salience-Preserving Color Removal

Amy Gooch

Sven Olsen

Jack Tumblin

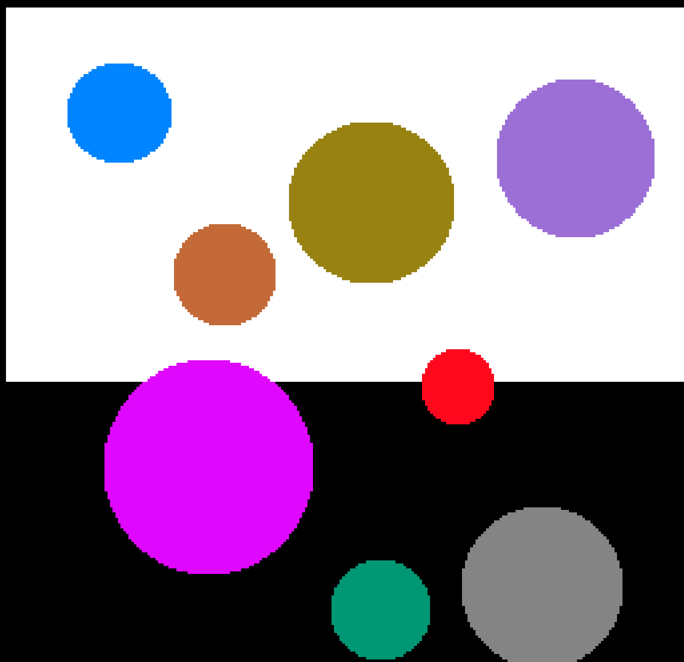
Bruce Gooch

Color

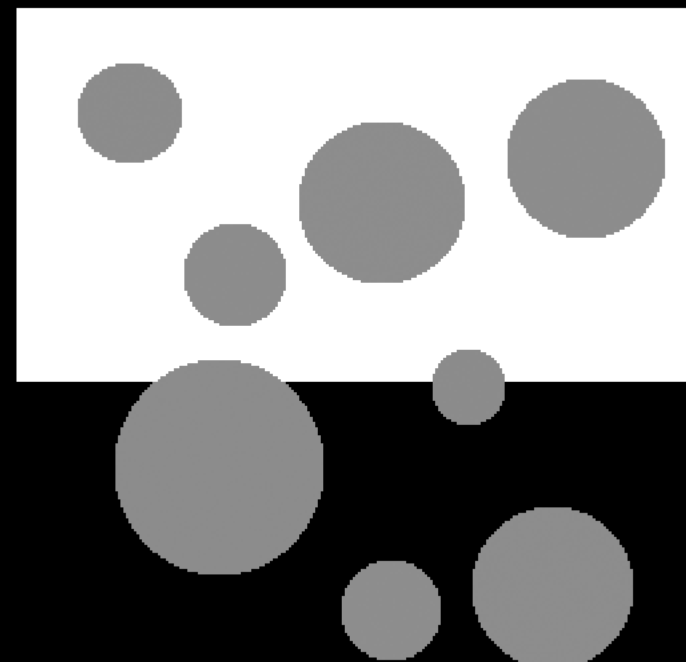
New Algorithm

Grayscale

Isoluminant Colors



Color



Grayscale

Traditional Methods:
Luminance Channels

Problem can not be solved by simply switching to a different space

CIE XYZ

YCrCb

Traditional Methods

SIGGRAPH2005

- Contrast enhancement & Gamma Correction
  - Doesn’t help with isoluminant values

Photoshop Grayscale

PSGray + Auto Contrast

New Algorithm

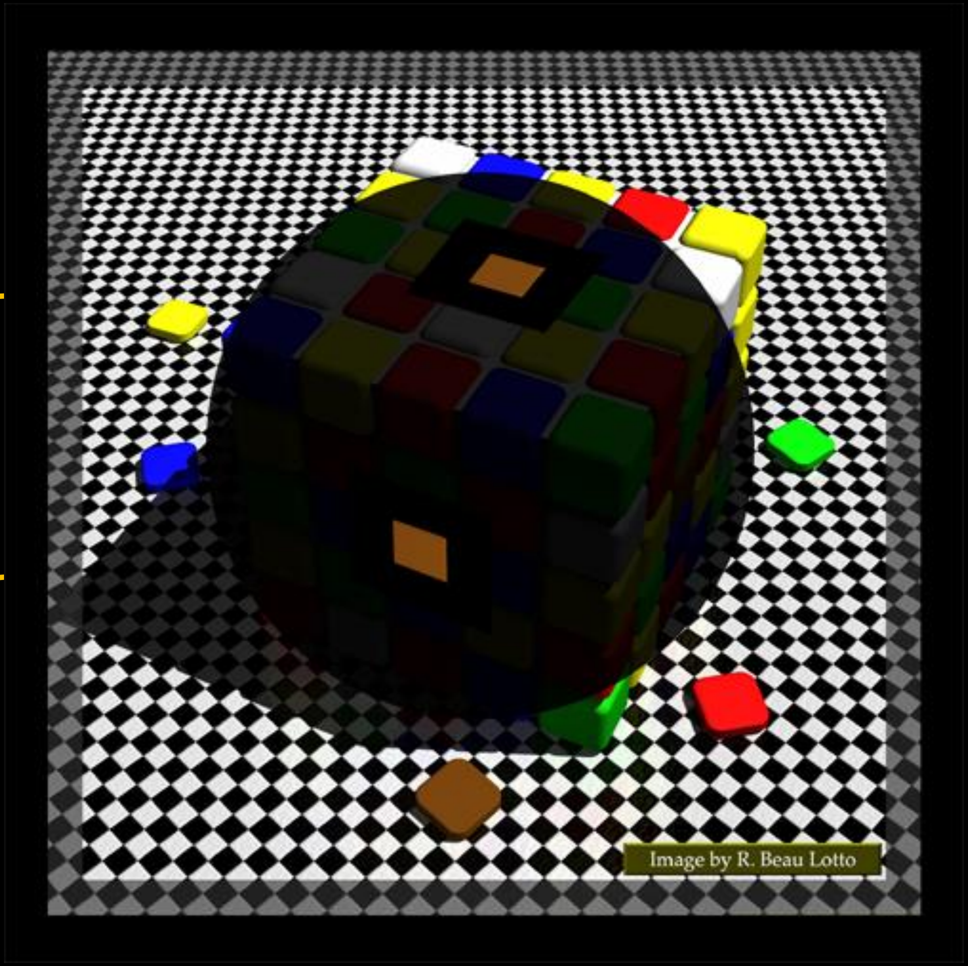
Goals

- Dimensionality Reduction
  - From tristimulus values to single channel

    Loss of information

- Maintain salient features in color image
  - Human perception

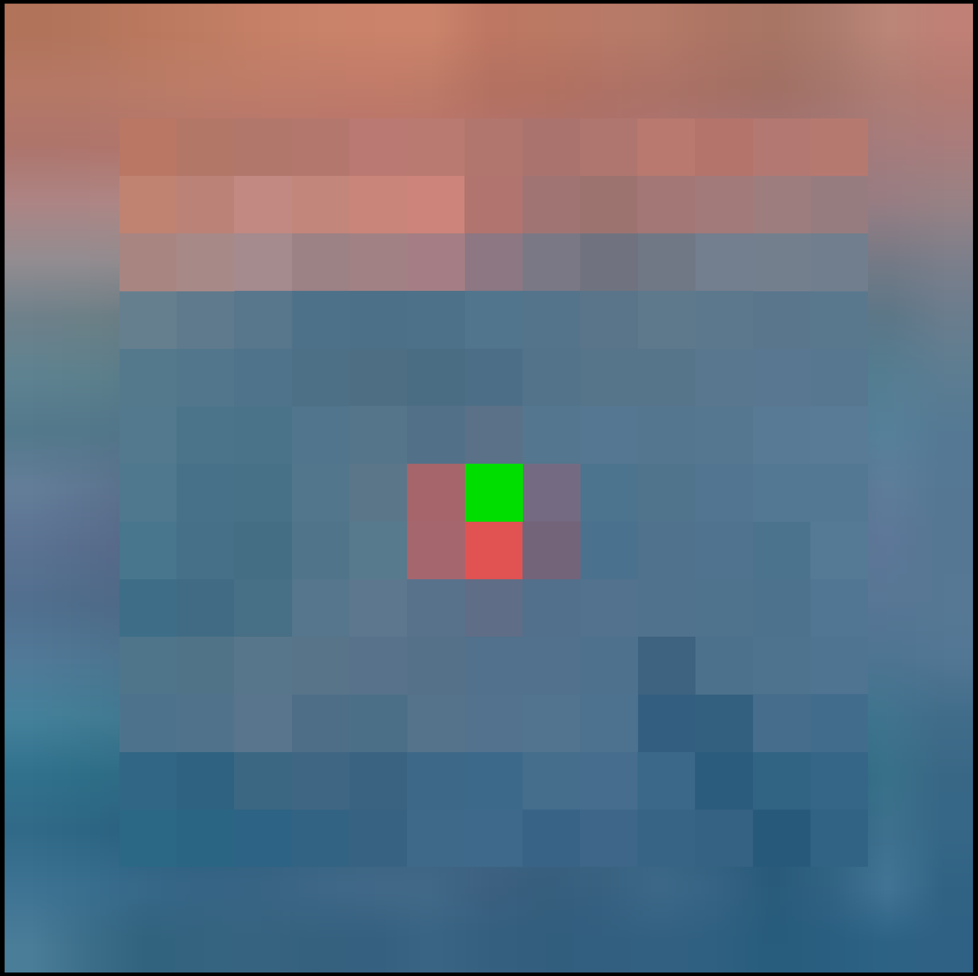
Relative differences



Color Illusion by
Lotto and Purves

http://www.lottolab.org

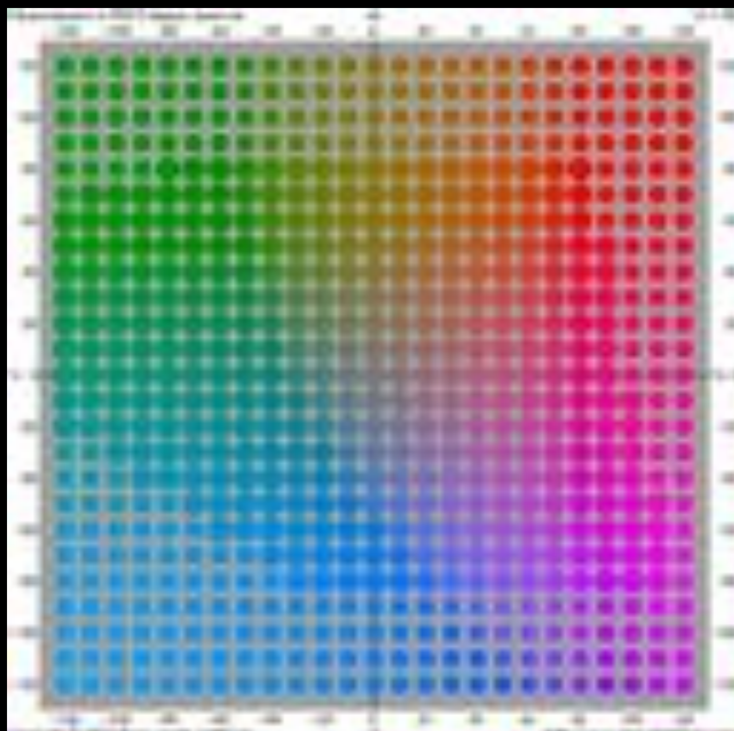
Challenge 1:
Influence of neighboring pixels



Challenge 2: Dimension and Size Reduction

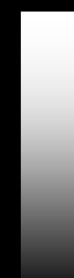
SIGGRAPH2005

120, 120



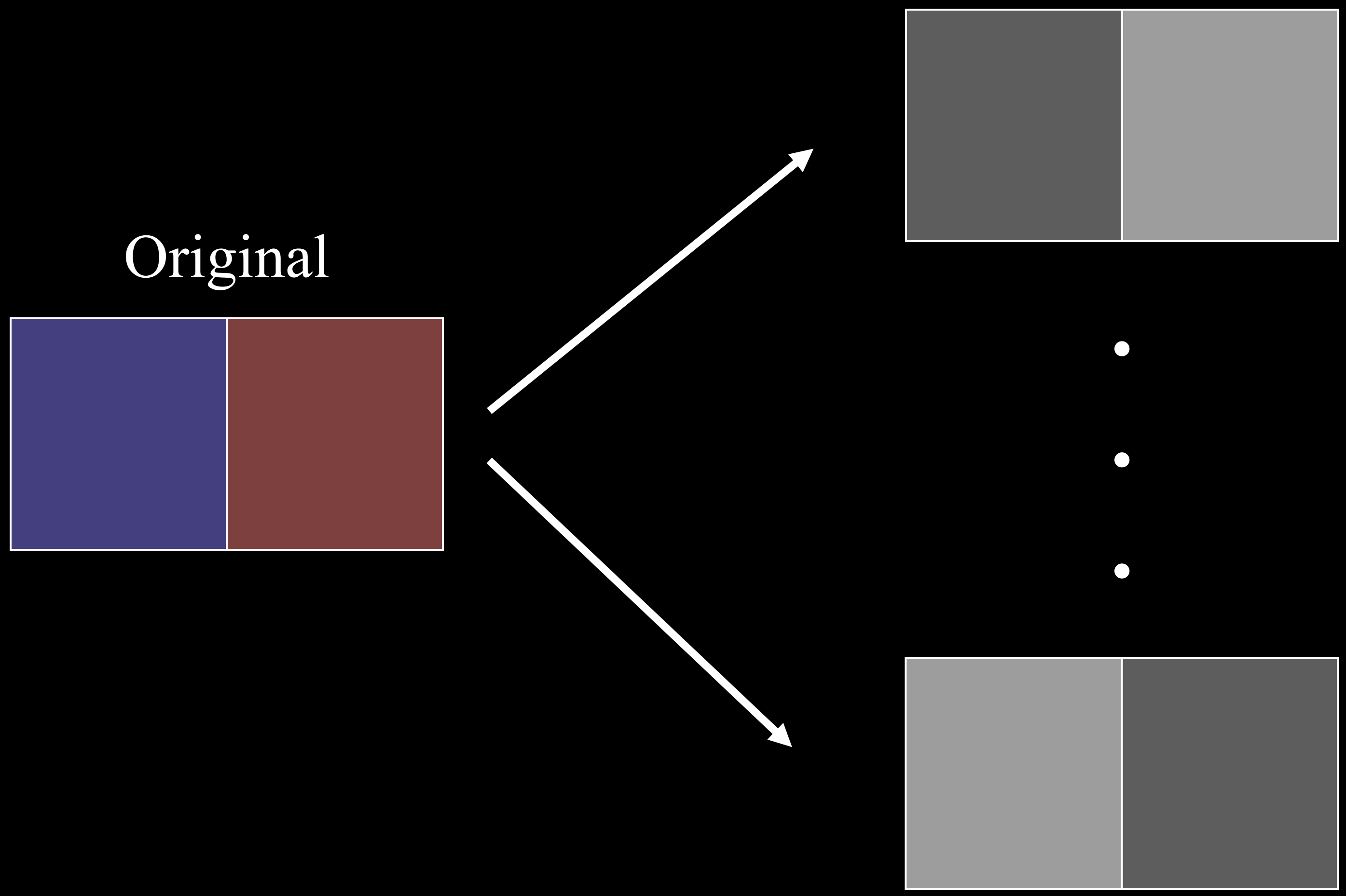
-120, -120

100



0

Challenge 3: Many Color2Gray Solutions



Algorithm Overview

- Convert to Perceptually Uniform Space
  - CIE L*a*b*
- Initialize image, *g*, with L channel
- For every pixel
  - Compute Luminance distance
  - Compute Chrominance distance

  δ_{ij}
- Adjust *g* to incorporate both luminance and chrominance differences

Color2Grey Algorithm

SIGGRAPH2005

Optimization:

$$\min \sum_{i} \sum_{j=i-\mu}^{i+\mu} \left((g_i - g_j) - \delta_{i,j} \right)^2$$

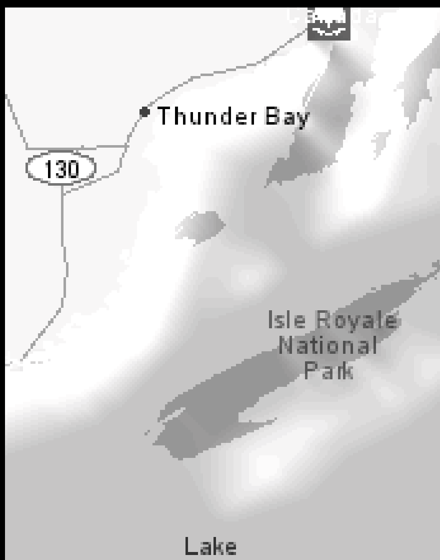
Parameters

μ : Radius of neighboring pixels

α : Max chrominance offset

θ : Map chromatic difference to increases or decreases in luminance values

μ : Neighborhood Size



$\mu = 2$

$\mu = 16$

μ= entire image

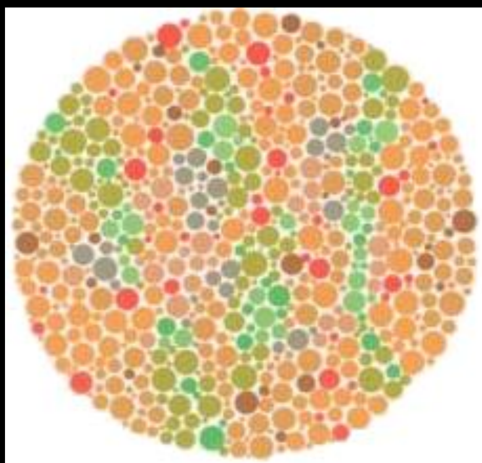
$\theta = 300^{o}$

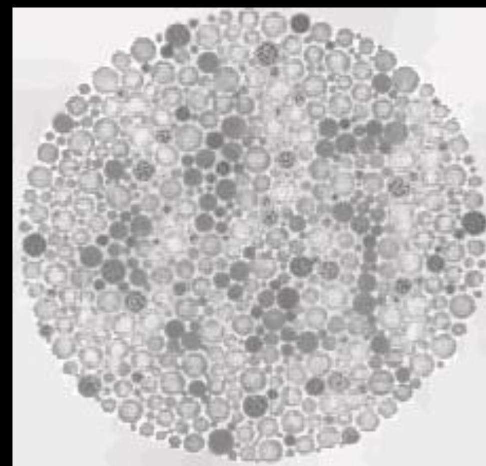
$\alpha = 10$

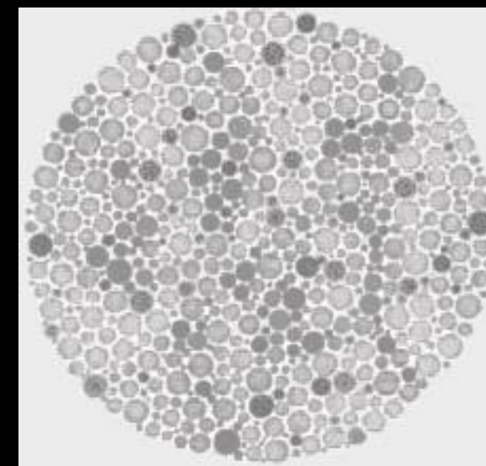
$\theta = 49^{o}$

$\alpha = 10$

μ : Neighborhood Size







$\mu = 16$

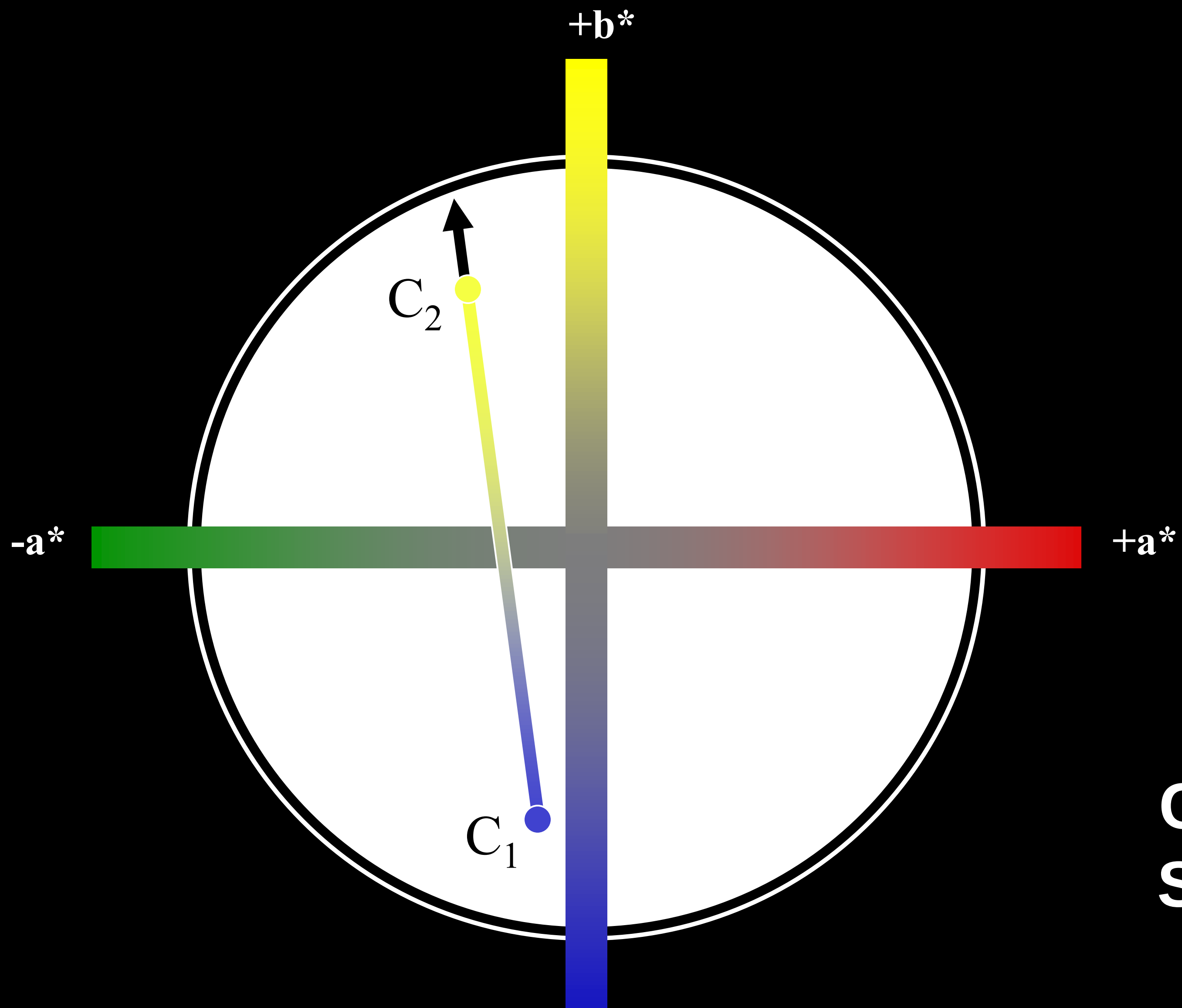
$\mu =$ entire image

Perceptual Distance

- Luminance Distance: $\Delta L_{ij} = L_i - L_j$
- Chrominance Distance: $||\overrightarrow{\Delta C_{ij}}||$

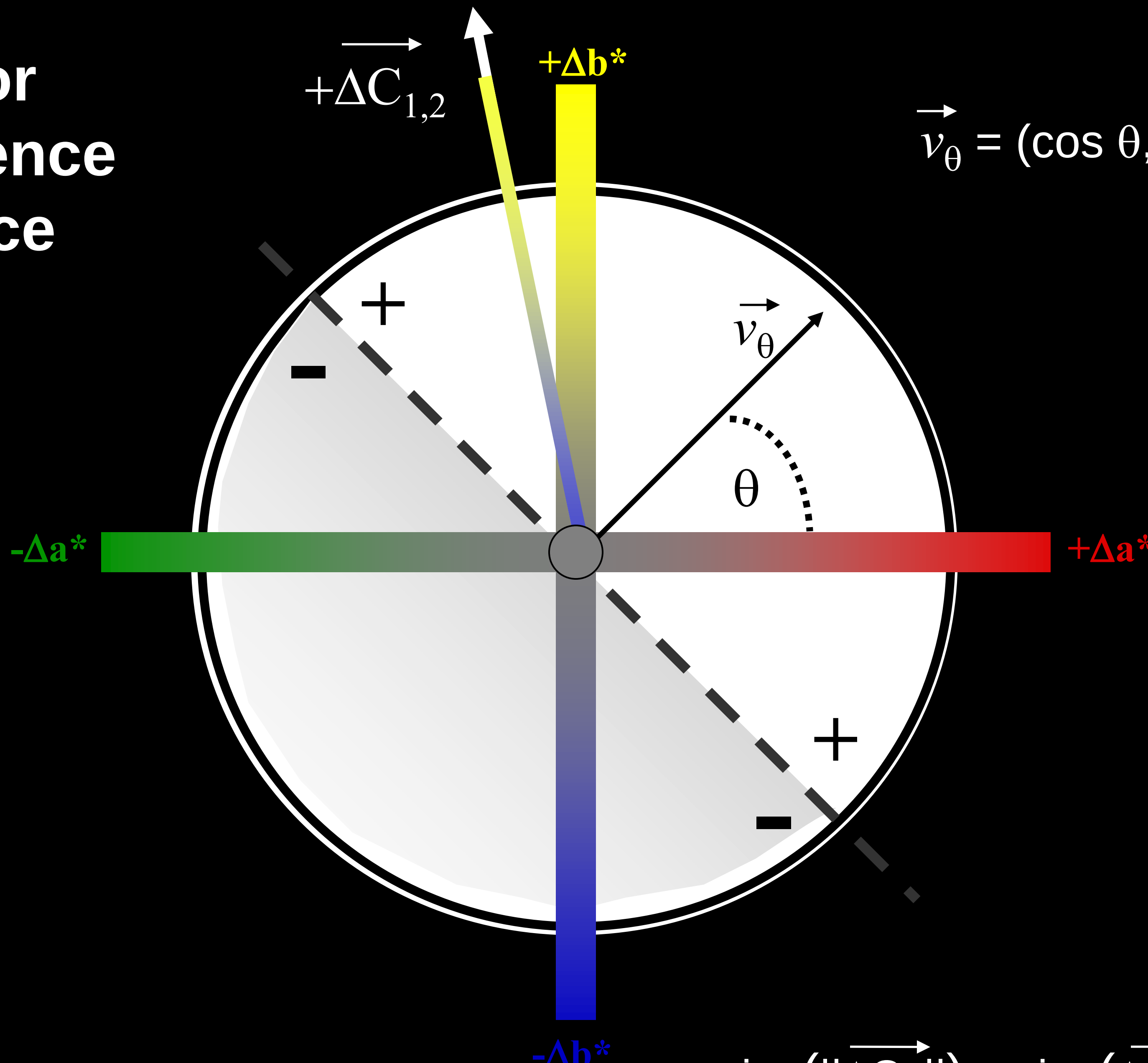
Problem: $||\overrightarrow{\Delta C_{ij}}||$ is unsigned

Map chromatic difference to increases or decreases in luminance values



Color Space

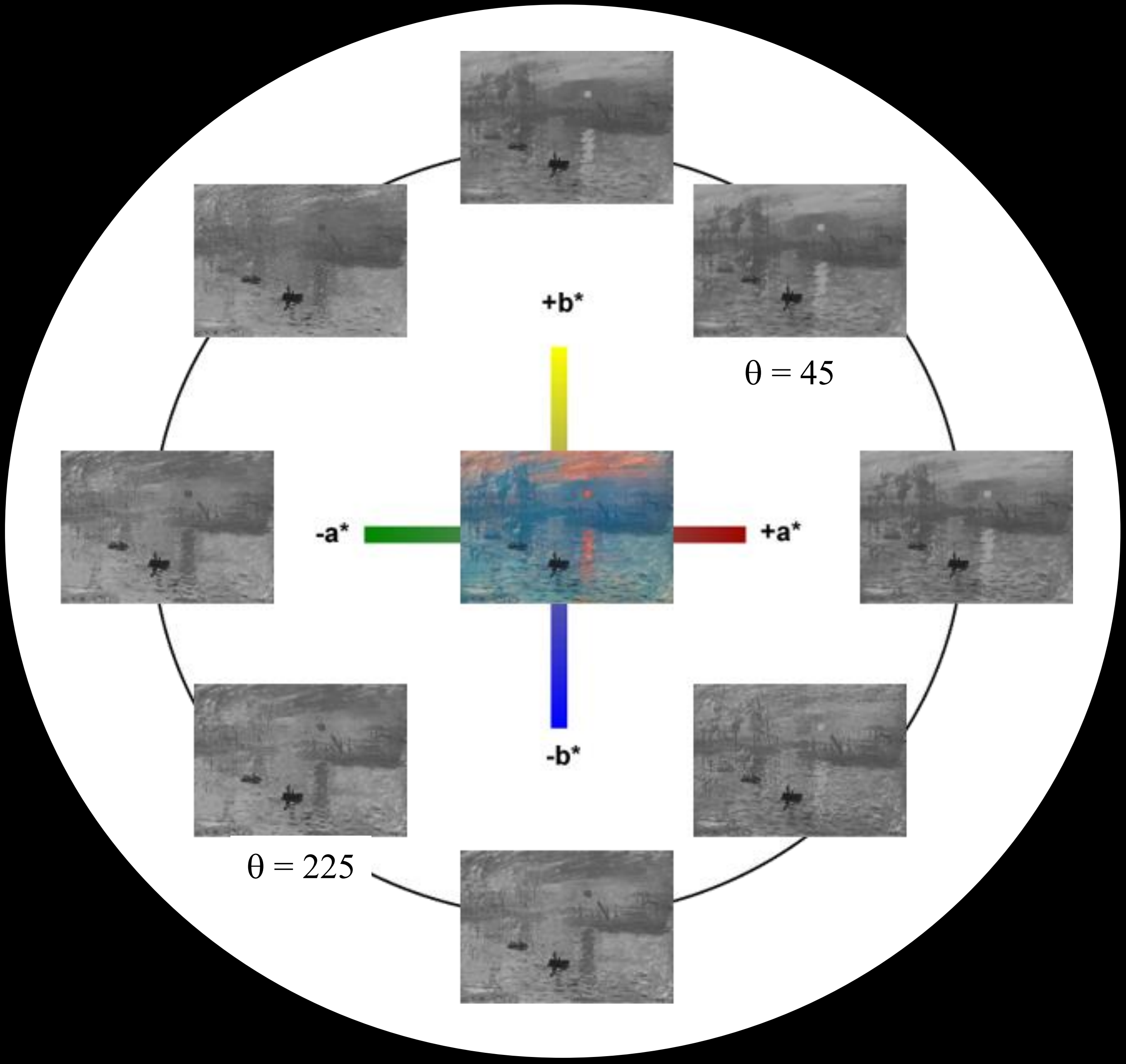
Color Difference Space

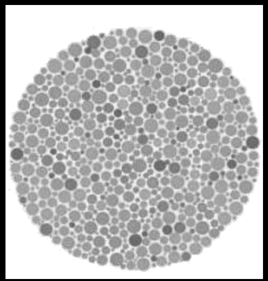


$$\vec{v}_\theta = (\cos\theta, \sin\theta)$$

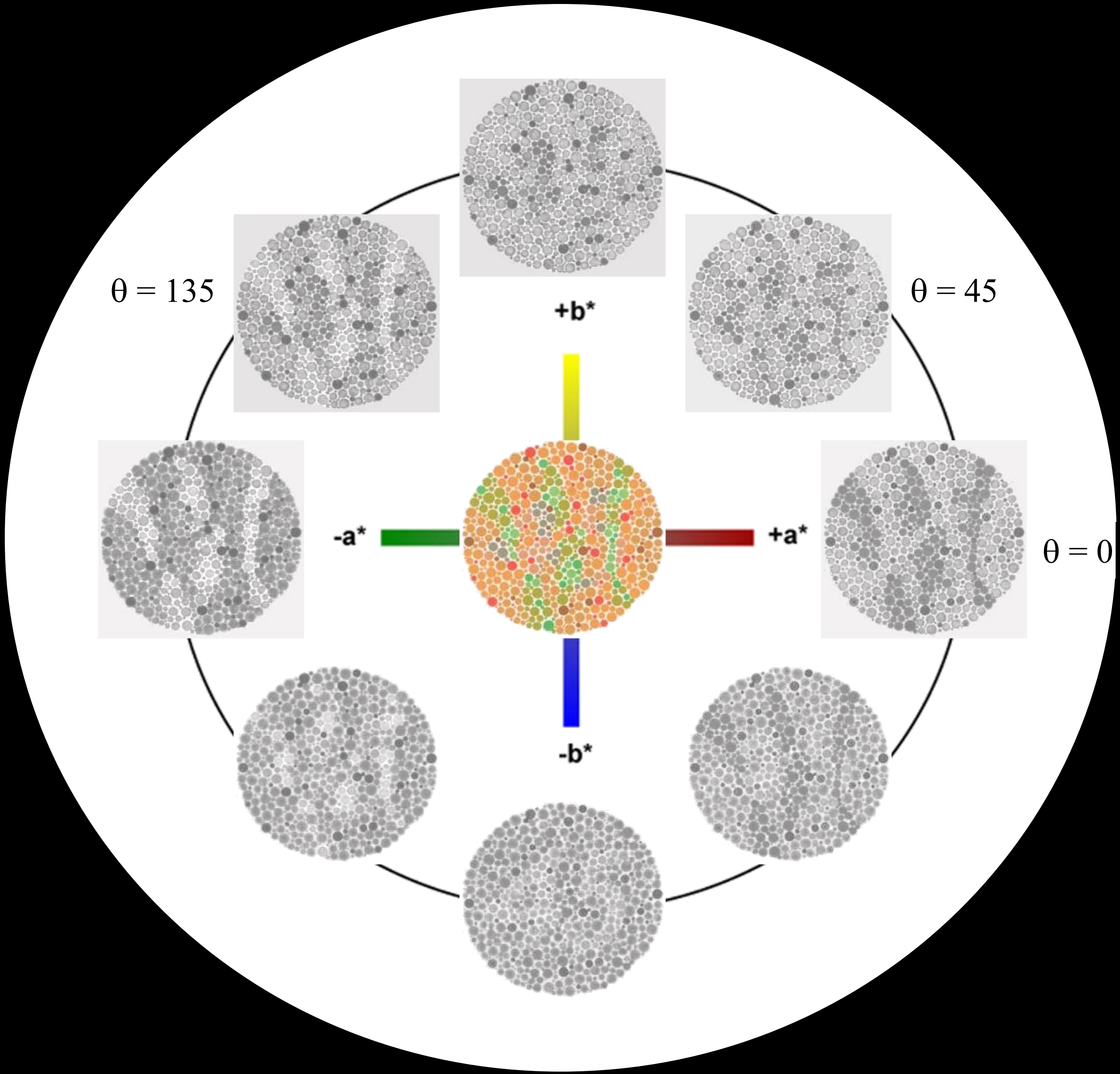
$$\mathrm{sign}\left(\|\overrightarrow{\Delta C_{i,j}}\|\right) = \mathrm{sign}\left(\overrightarrow{\Delta C_{i,j}} \cdot \vec{v}_\theta\right)$$

Photoshop Grayscale





Grayscale



How to Combine Chrominance and Luminance

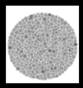
$\delta_{ij} = \quad \Delta L_{ij}$ **(Luminance)**

How to Combine Chrominance and Luminance

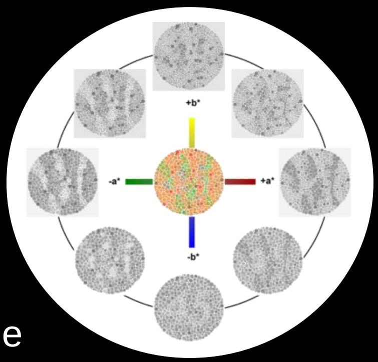
$$\delta_{ij} = \begin{cases} \Delta L_{ij} & \text{(Luminance)} \quad \text{if } |\Delta L_{ij}| > \|\Delta C_{ij}\| \\ \|\Delta C_{ij}\| & \text{(Chrominance)} \end{cases}$$

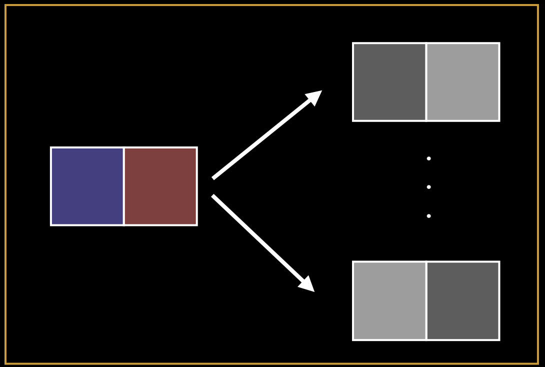
How to Combine Chrominance and Luminance

$$\delta(\alpha,\theta)_{ij} = \begin{cases} \Delta L_{ij} & \text{if } |\Delta L_{ij}| > \|\Delta C_{ij}\| \\ \|\Delta C_{ij}\| & \text{if } \Delta C_{ij} \cdot v_\theta \geq 0 \\ -\|\Delta C_{ij}\| & \text{otherwise} \end{cases}$$



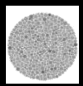
Grayscale



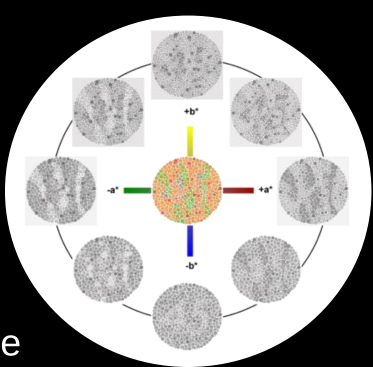


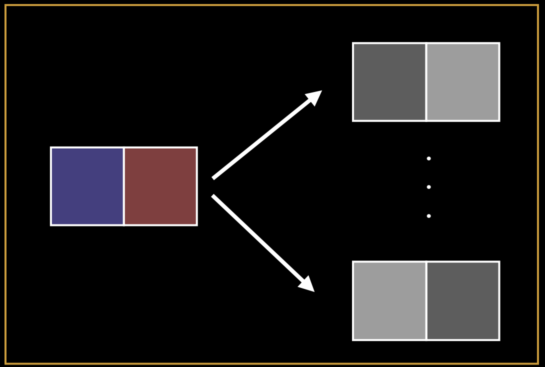
How to Combine Chrominance and Luminance

$$\delta(\alpha,\theta)_{ij} = \begin{cases} \Delta L_{ij} & \text{if } |\Delta L_{ij}| > \text{crunch}(\|\Delta C_{ij}\|) \\ \text{crunch}(\|\Delta C_{ij}\|) & \text{if } \Delta C_{ij} \cdot v_\theta \geq 0 \\ \text{crunch}(-\|\Delta C_{ij}\|) & \text{otherwise} \end{cases}$$

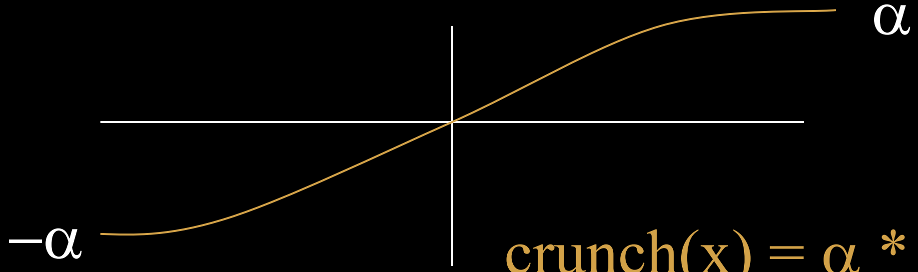


Grayscale





α: Chromatic variation maps to luminance variation



$$\text{crunch}(x) = \alpha * \tanh(x/\alpha)$$

$\alpha = 5$

$\alpha = 10$

$\alpha = 25$

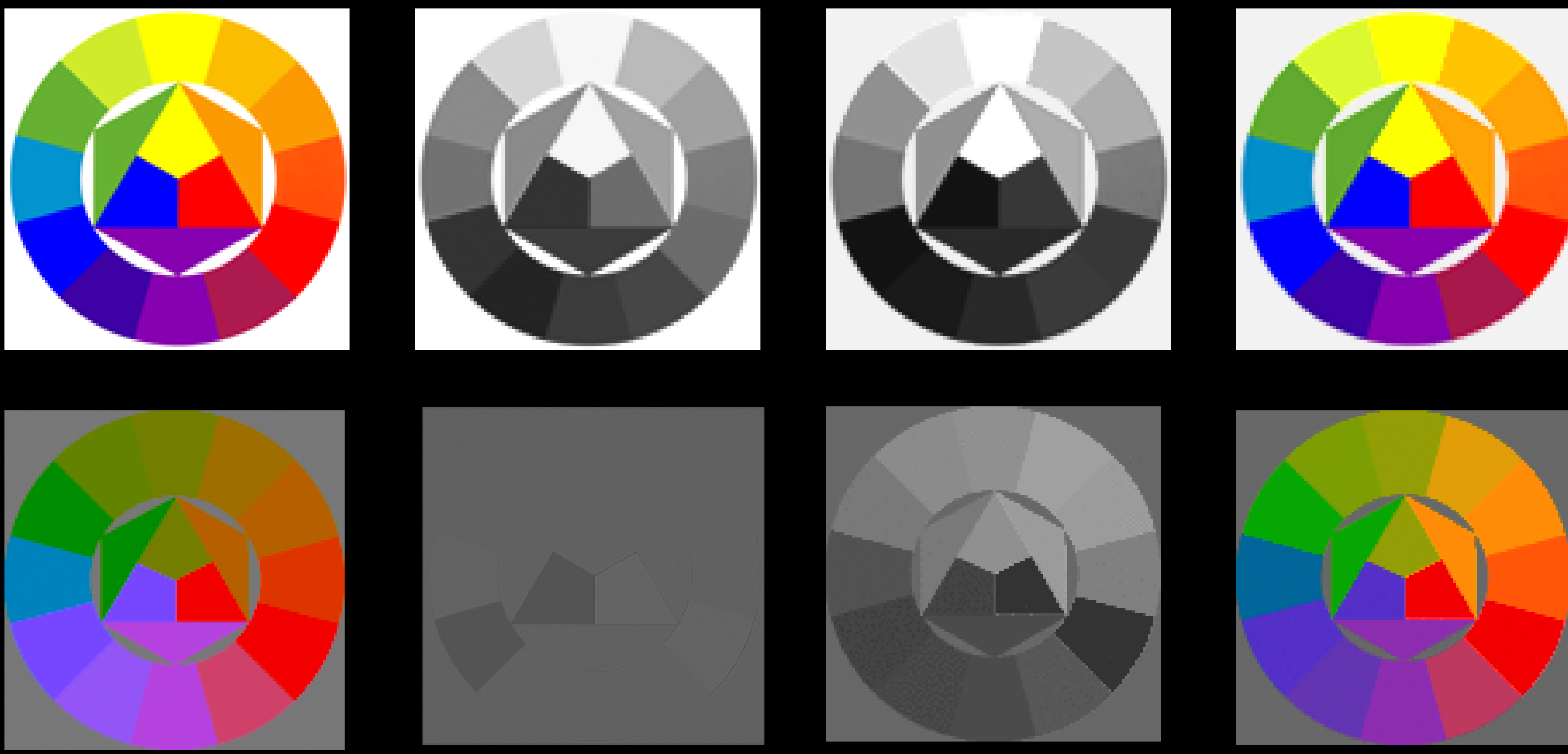
Color2Grey Algorithm

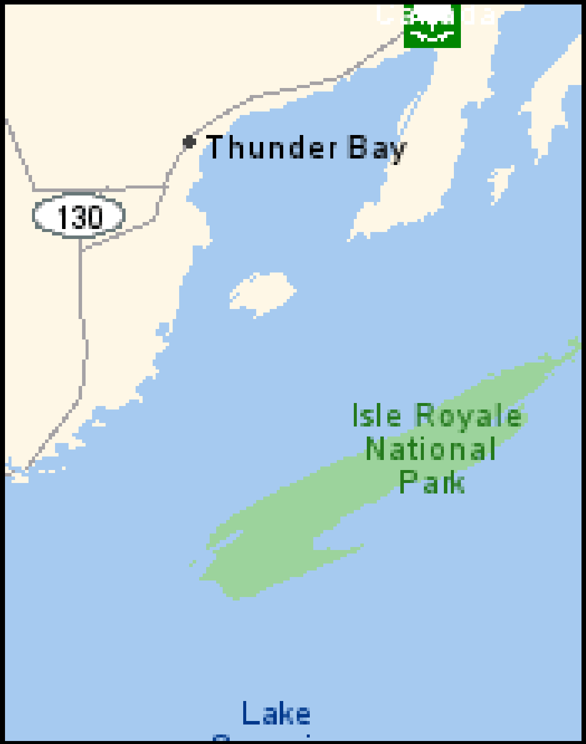
Optimization:

$$\min \sum_{i} \sum_{j=i-\mu}^{i+\mu} \left((g_i - g_j) - \delta_{i,j} \right)^2$$

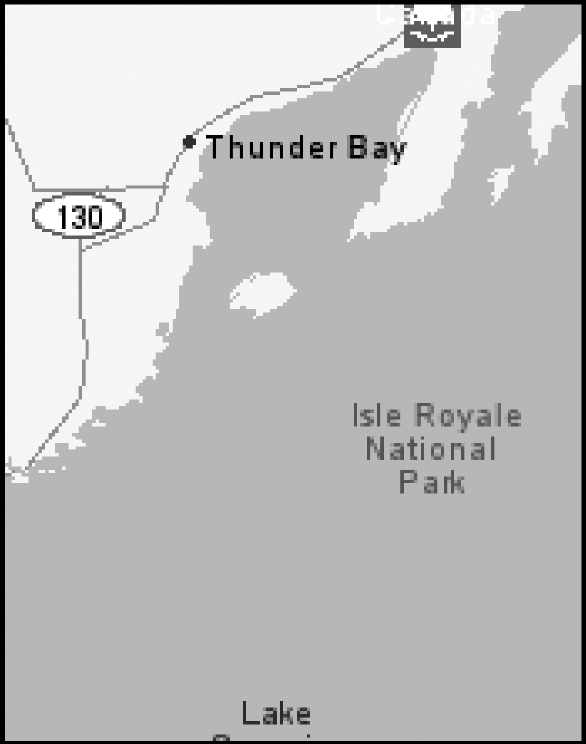
Results

Original	Photoshop Grey	Color2Grey	Color2Grey + Color





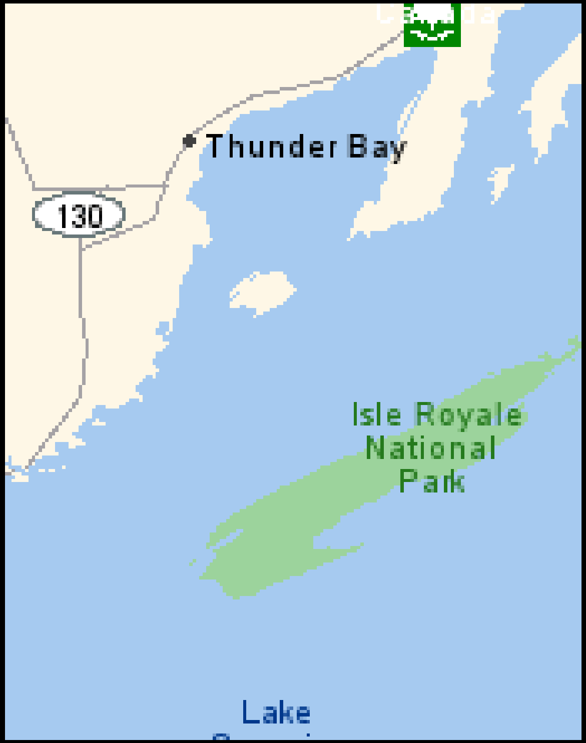
Original



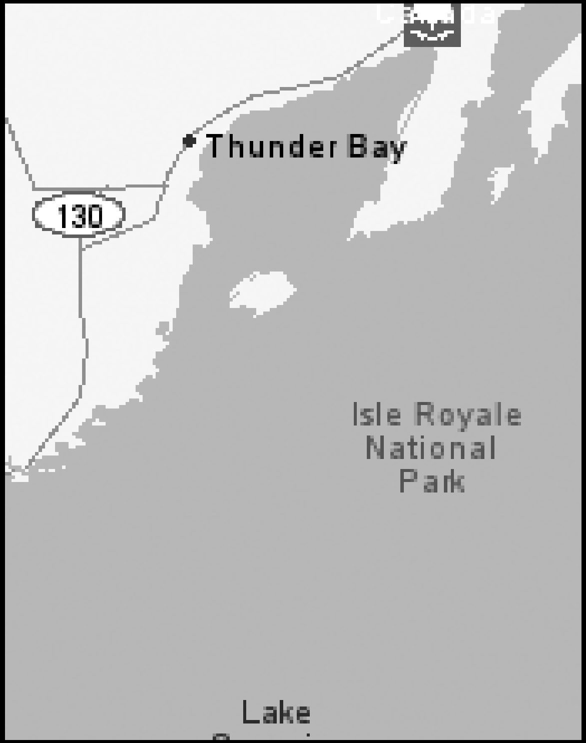
PhotoshopGrey

Color2Grey

SIGGRAPH2005



Original



PhotoshopGrey

Color2Grey+Color

Original

PhotoshopGrey

Color2Grey

Original PhotoshopGrey Color2Grey

Implementation Performance

- Image of size S x S
  - $O(\mu^2 S^2)$ or $O(S^4)$ for full neighborhood case
    - 12.7s 100x100 image
    - 65.6s 150x150 image
    - 204.0s 200x200 image

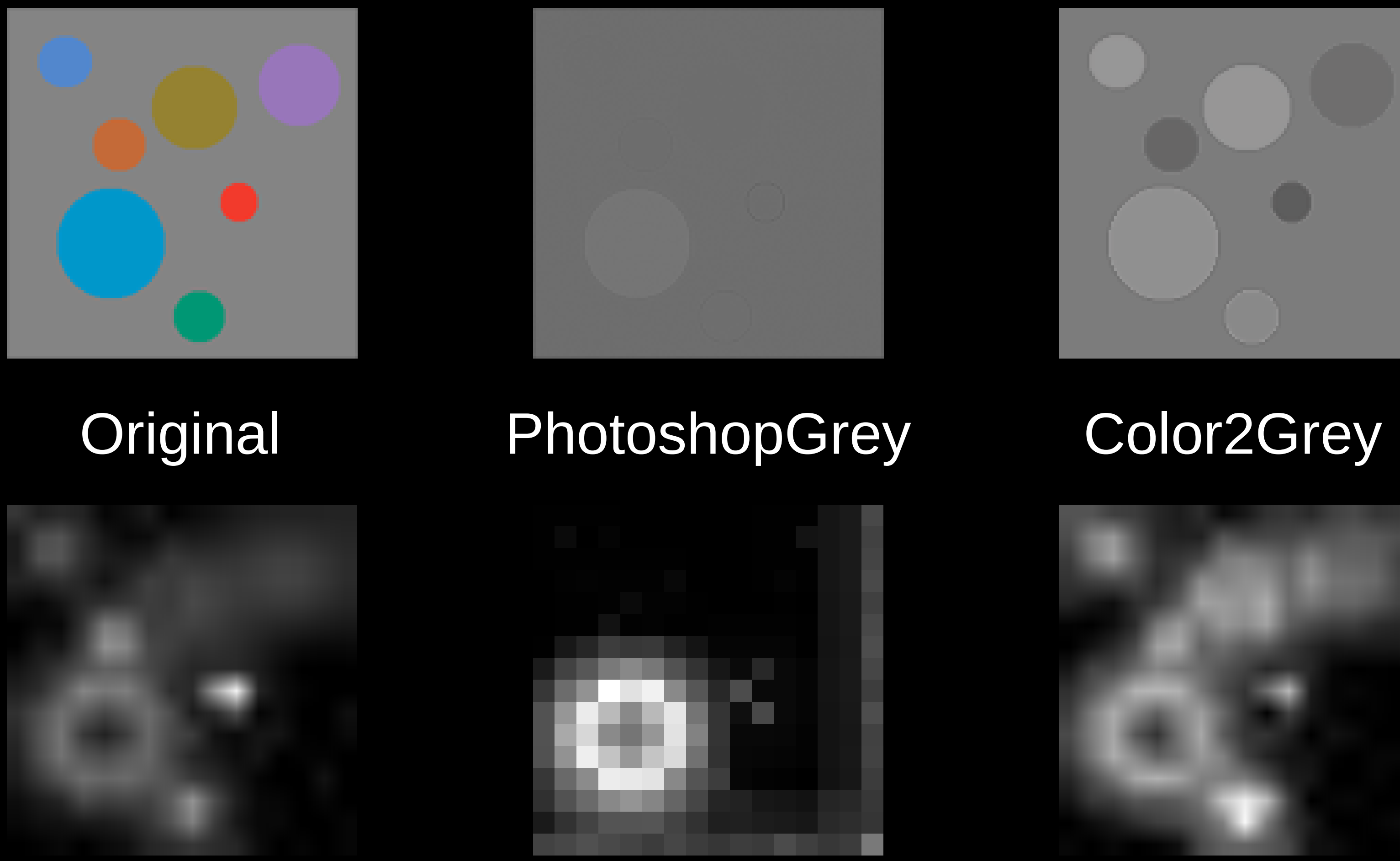
    Athlon 64 3200 CPU
  - GPU implementation
    - $O(S^2)$ ideal, really $O(S^3)$
      - 2.8s 100x100
      - 9.7s 150x150
      - 25.7s 200x200

      NVIDIA GeForce GT6800

Future Work

- Faster
  - Multiscale
- Smarter
  - Remove need to specify θ
    - New optimization function designed to match both signed and unsigned difference terms
  - Image complexity measures
- Animations/Video

Validate "Salience Preserving"



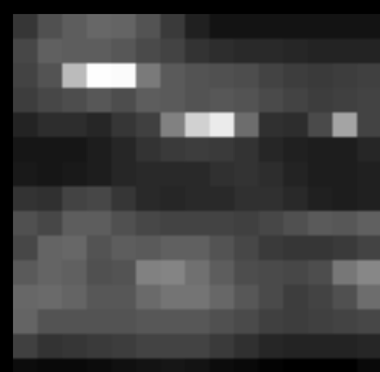
Apply Contrast Attention model by Ma and Zhang 2003

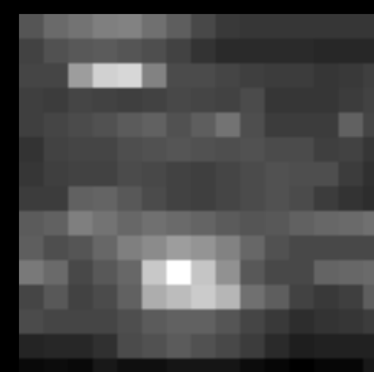
Validate "Salience Preserving"

Original

PhotoshopGrey

Color2Grey





Student paper presentation

Joint bilateral Upsampling

J. Kopf, M. Cohen, D. Lischinski, and M. Uyttendaele
SIGGRAPH 2007

Presenter: Singh, Harmandeep

Next Time

- Re-lighting
- Student paper presentation
  - Image denoising: Can plain Neural Networks compete with BM3D?

    Harold C. Burger, Christian J. Schuler, and Stefan Harmeling
    IEEE CVPR 2012
  - Harish, Achyutha Nelamangala