Color Image Processing

Pengolahan Citra

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Review

- Color Vision
- Additive Colors
- Color Theory
- Complementary Afterimage
- Color Order Systems / Color Models
    - Why?
    - Examples?

Pengolahan Citra Berwarna

- Motivasi
  - Warna merupakan deskriptor yang sangat berguna
  - Warna dapat membantu proses identifikasi dan ekstraksi objek pada citra

Pengolahan Citra Berwarna

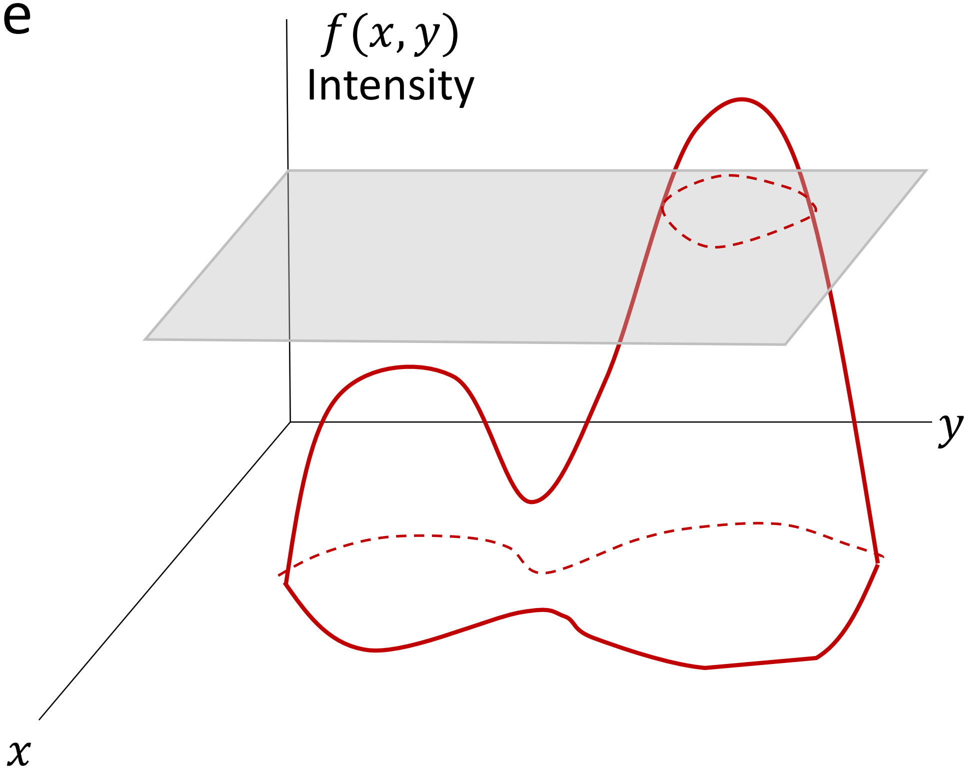
- Pengolahan citra berwarna:
  - Pengolahan pseudocolor
    - Citra diperoleh dengan cara *meng-assign* warna pada kisaran keabuan.
  - Pengolahan full-color
    - Citra diperoleh dengan sensor full-color (kamera TV berwarna atau scanner berwarna, dll)

Pengolahan Citra *Pseudocolor*

- Pseudocolor / *false color* : citra dibuat dengan cara meng-*assign* suatu warna kepada suatu kisaran keabuan pada citra monokrom.
- Untuk apa?
  - Visualisasi
  - Interpretasi kejadian *gray-scale* dalam citra
- Mengapa pseudocolor lebih baik daripada citra grayscale?
  - Manusia mampu membedakan ribuan warna
  - Manusia mampu membedakan puluhan level keabuan

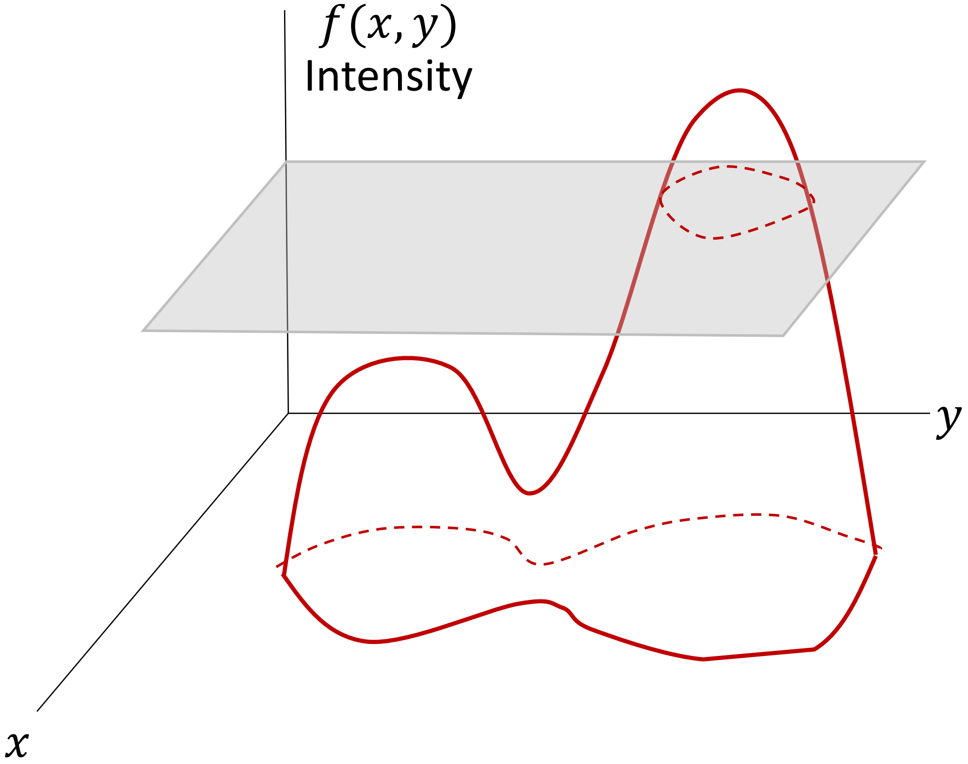
Intensity Slicing /Density Slicing / Color Coding

- If a grayscale image is represented as a 3D function
- We can the intensity with planes parallel to the coordinate plane

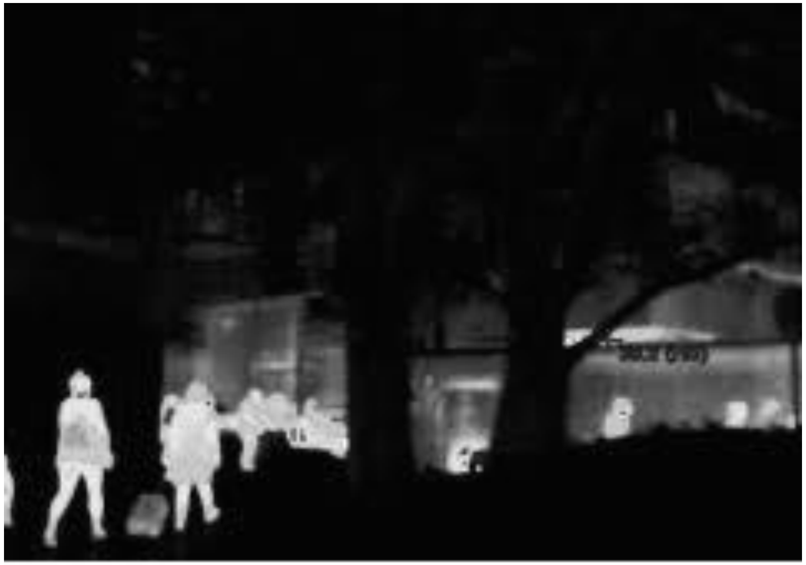


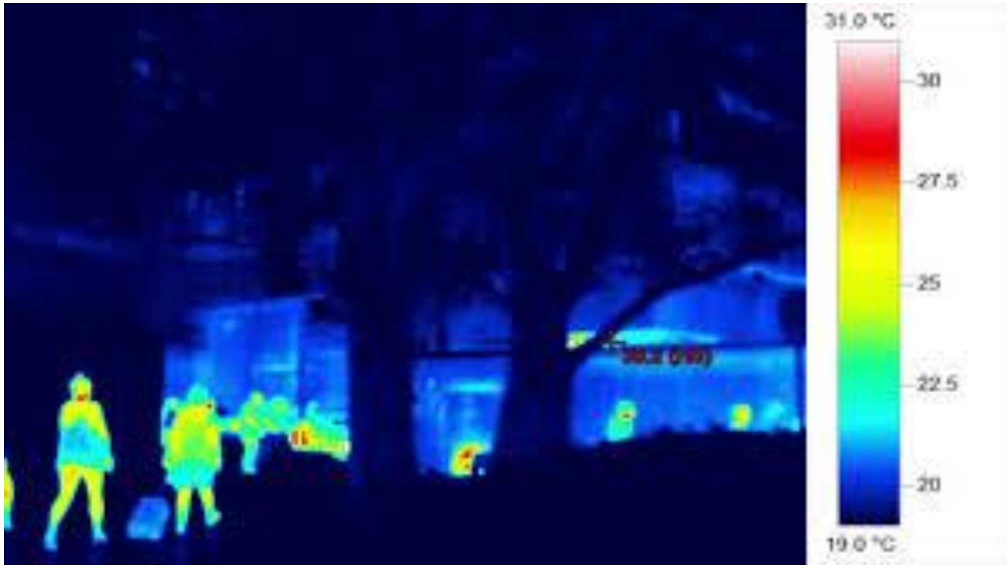
Intensity Slicing /Density Slicing / Color Coding (2)

- We can then assign values to each side of the plane
- We can have as many planes as we need



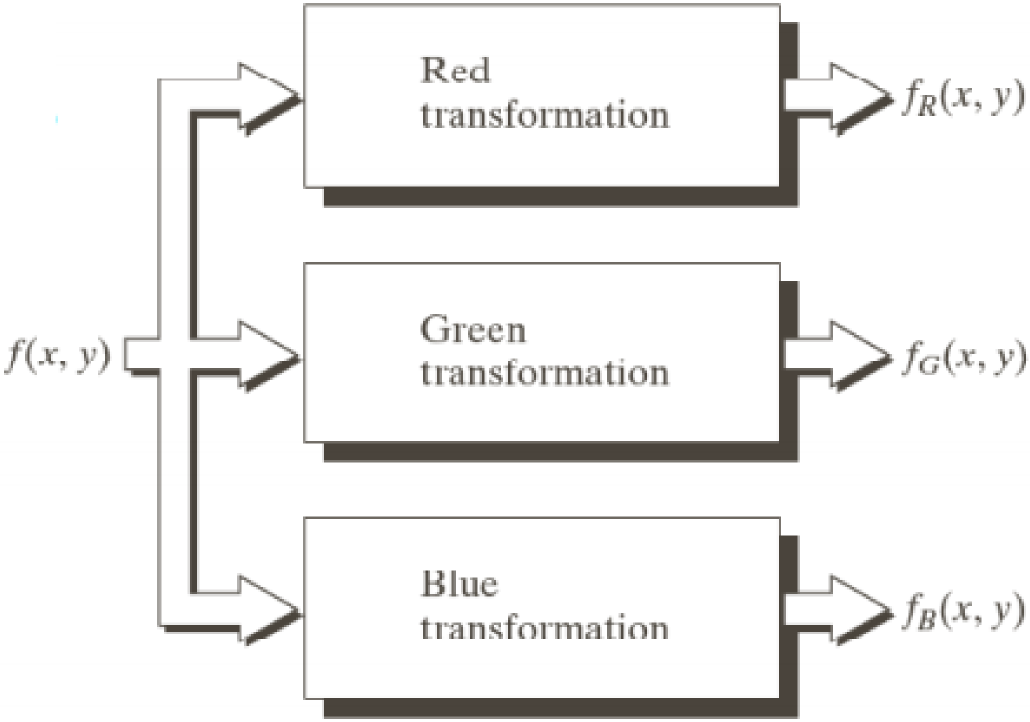
Pseudocolor in Thermal Infrared





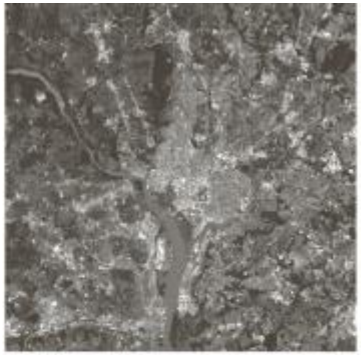
Intensity to Color Transformation

- Process 1-channel into 3-channels via 3 transformations



Intensity to Color Transformation (2)

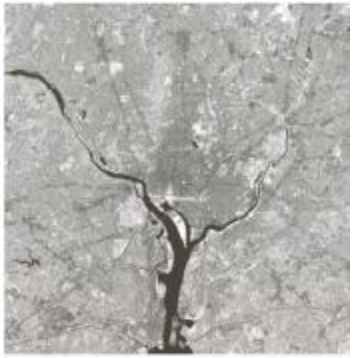
- Use more than 1 grayscale image → Multispectral images



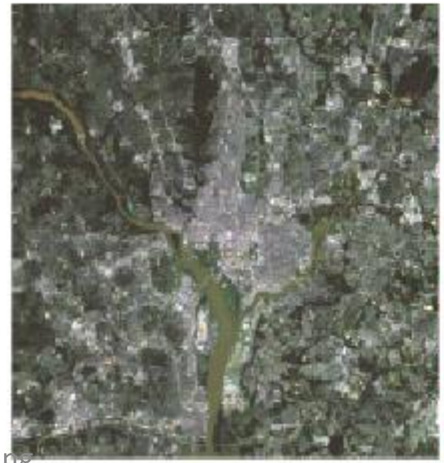
R

G

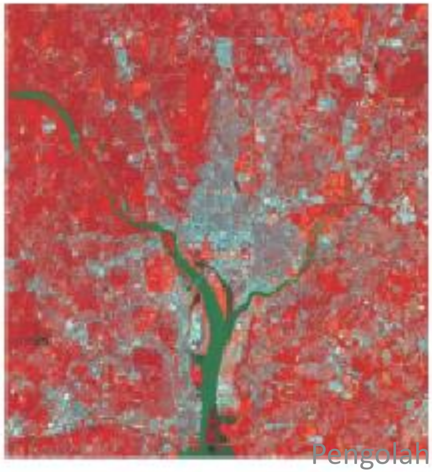
B



NearIR



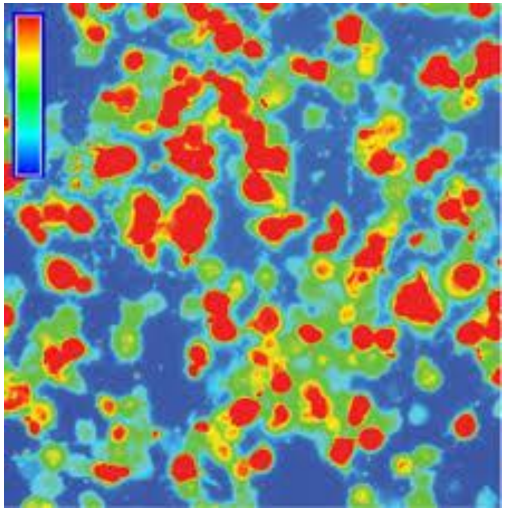
R-G-B

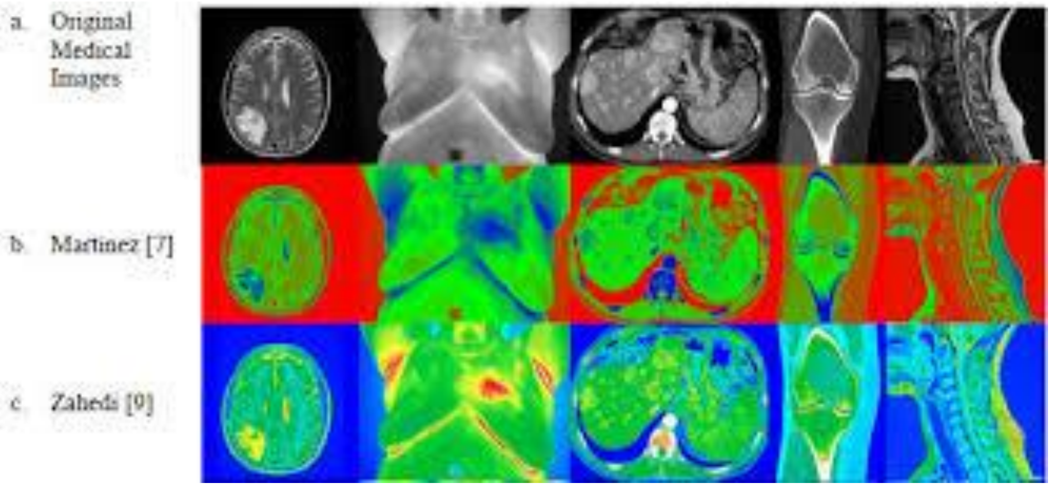


NearIR – G -B

Brainstorming

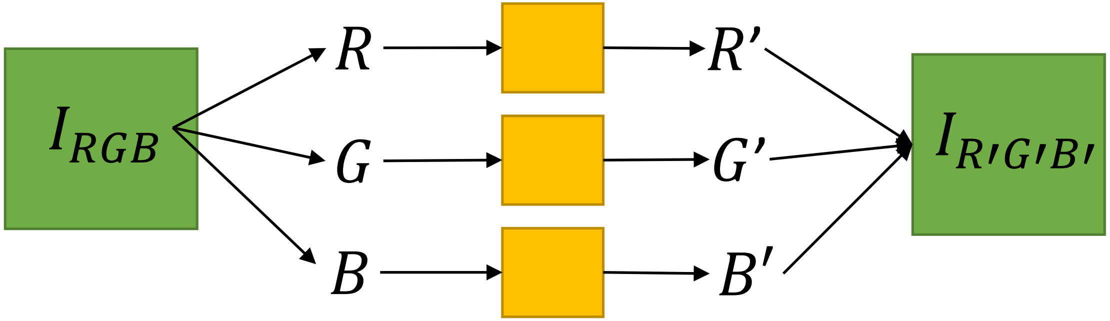
- Any other ideas?





Full-Color Image Processing

- Approaches:
  - Processing per channel

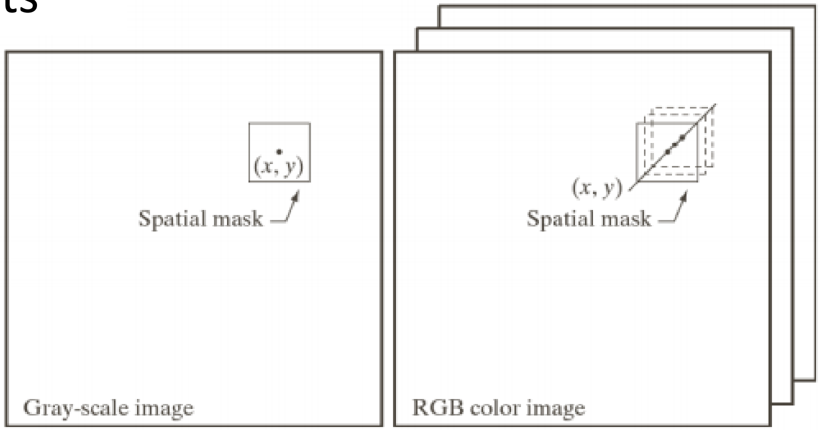


  - Processing 1 pixel [R G B] as a vector

$$I(x,y) = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

Full-Color Image Processing (2)

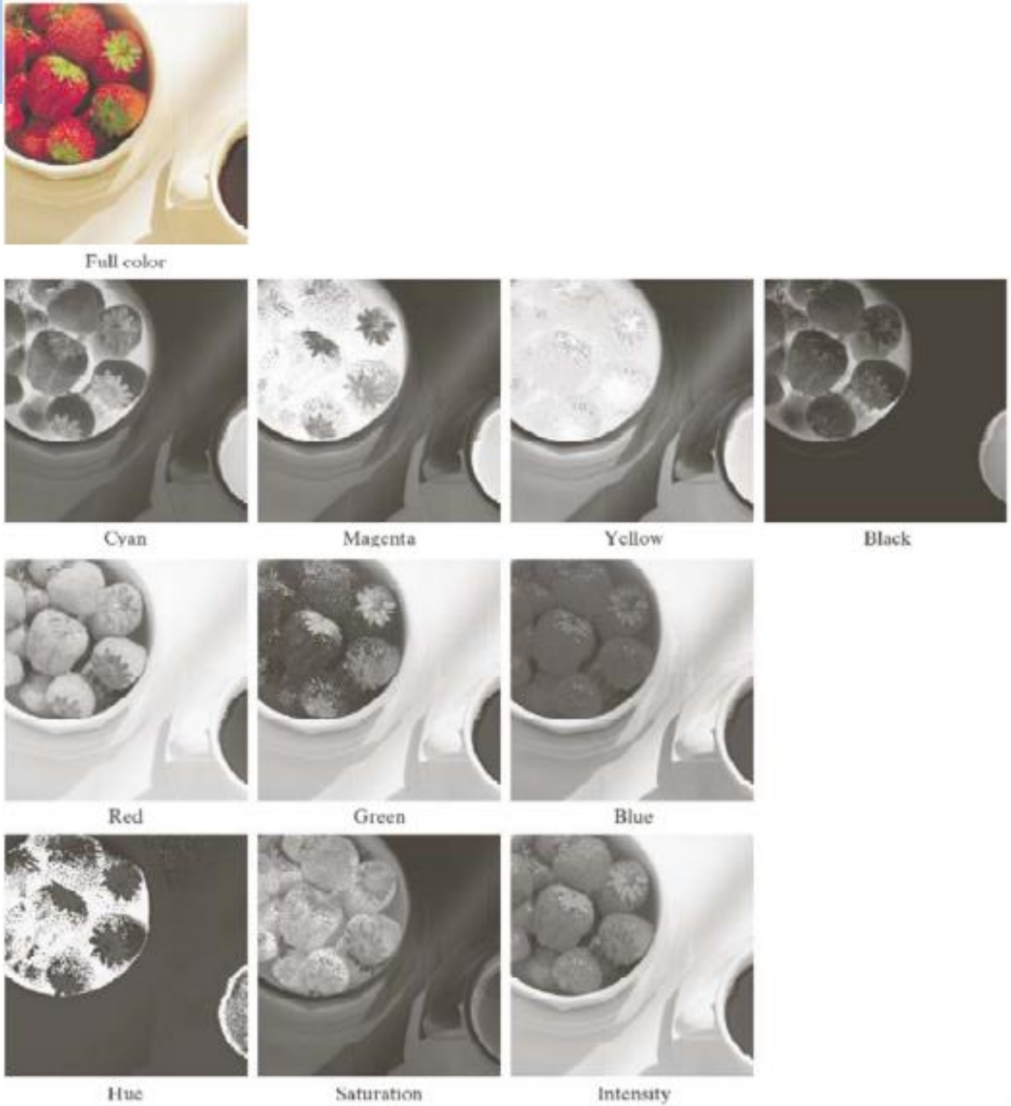
- Processing per channel and processing vectors: equivalency?
- 2 conditions:
  - The process / operation must be applicable to both vectors and scalars
  - The operation on 1 component must be independent of other components



Not all operations process this two approaches equivalently

Color Transformation / Color Mapping

- *Color transformation* yang di maksud di sini adalah transformasi dalam 1 buah color model saja.
    - (Bukan antar color model seperti RGB-HSV)



Color Transformation / Color Mapping

$$g(x, y) = T[f(x, y)]$$

- Limited to

$$s_i = T_i(r_1, r_2, \ldots r_n), \mathrm{i} = 1{,}2{,}3, \ldots \mathrm{n}$$

  - Where s_i and r_i denote the color components at position (x, y).
  - $\{T_1, T_2, \ldots T_n\}$ is a set of transformations
  - n is the number of dimensions needed to represent the color space, e.g. RGB: $n = 3$, and $r_1 = R, r_2 = G, and\ r_3 = B$

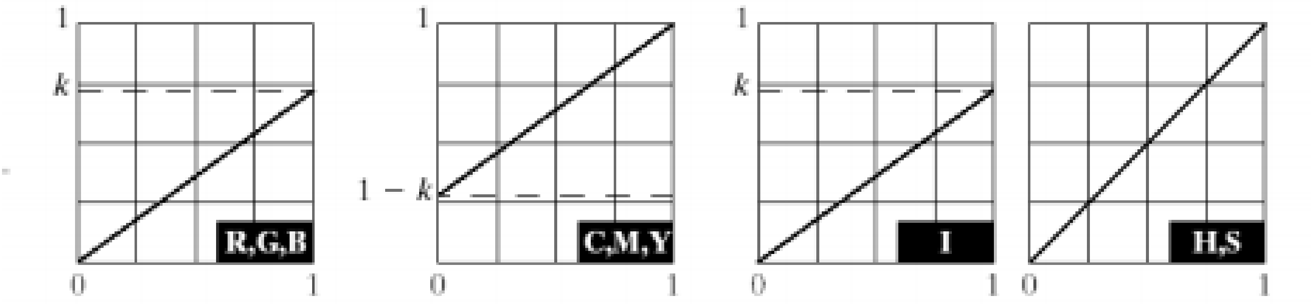
Color Transformation Example

- Example: change the intensity of the full color image

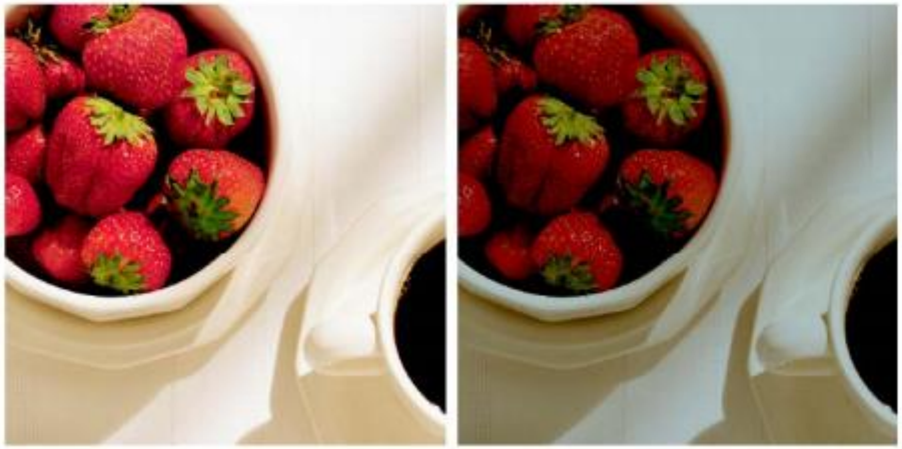
$$g(x,y) = k.f(x,y)$$

- Depends on color model
  - Recall $s_i = T_i(r_1, r_2, \dots r_n), \mathrm{i} = 1,2,3, \dots \mathrm{n}$
  - HSI $I \rightarrow s_3 = kr_3$
  - RGB $R, G, B \rightarrow s_i = kr_i, \qquad i = 1,2,3$
  - CMY $C, M, Y \rightarrow s_i = kr_i, +(1-k), \qquad i = 1,2,3$

Color Transformation Example (2)

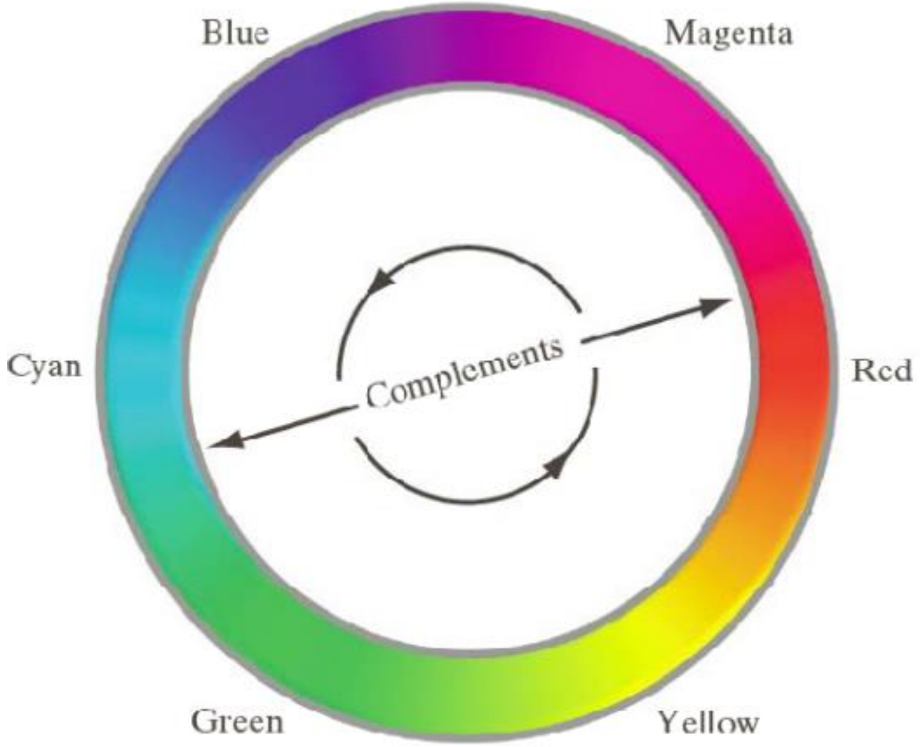


- $k = 0.7$



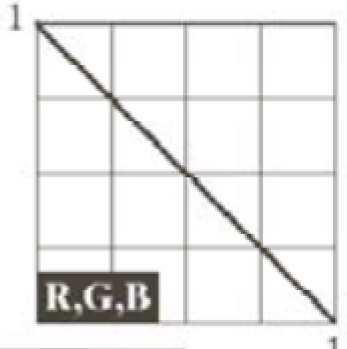
Color Complements

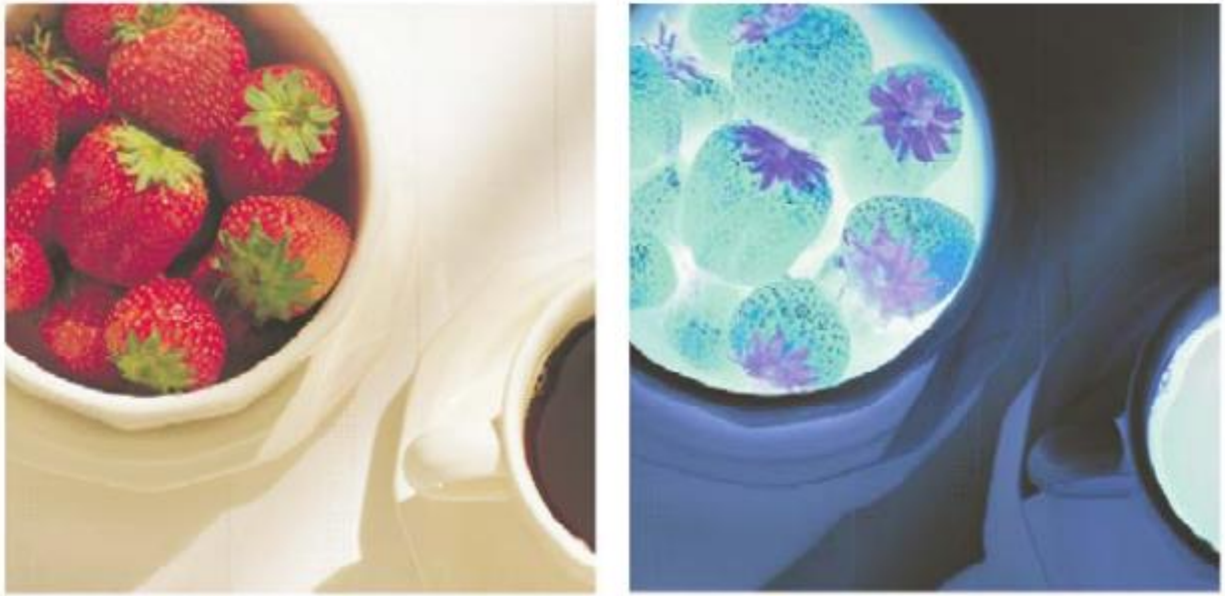
- The hues directly opposite of one another on Newton’s color circle



Color Complements (2)

- Analogous to the gray-scale negatives





Color Slicing

- Attempts to highlight a specific range of colors.

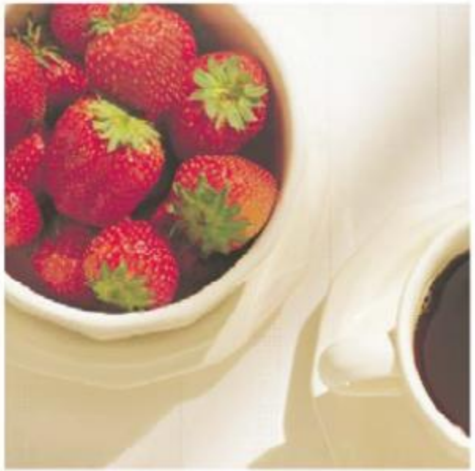
- Idea:
  - Display the colors of interest so that they stand out
  - Use the resulting image as a mask for further processing

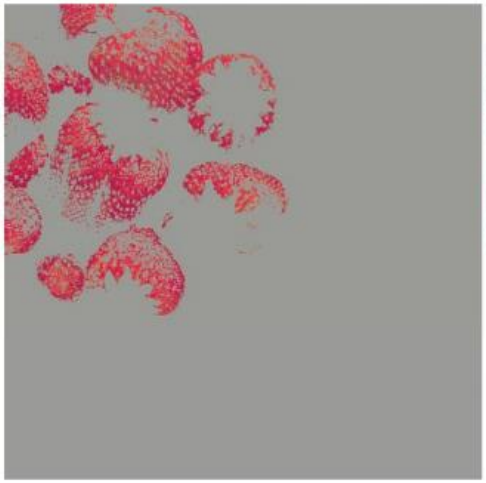
- How?
  - Map the colors of interest to a eye-catching color
  - Map the colors outside of the range of interest to a neutral color

Color Slicing (2)

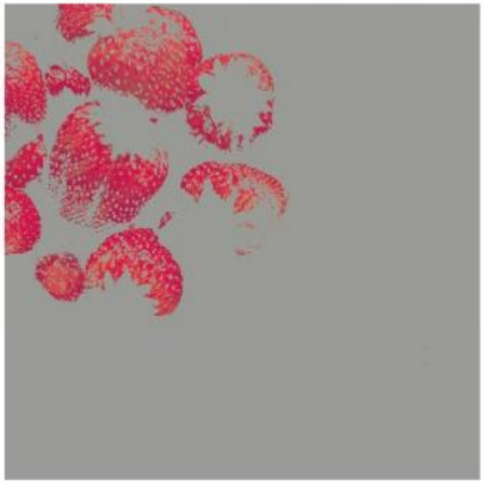
- Set a color of interest $(a_1, a_2, a_3 .. a_n)$ and allow a threshold of colors near it to remain, while cancelling out the rest

$a = (0.6863, 0.1608, 0.1922)$ to detect edible objects



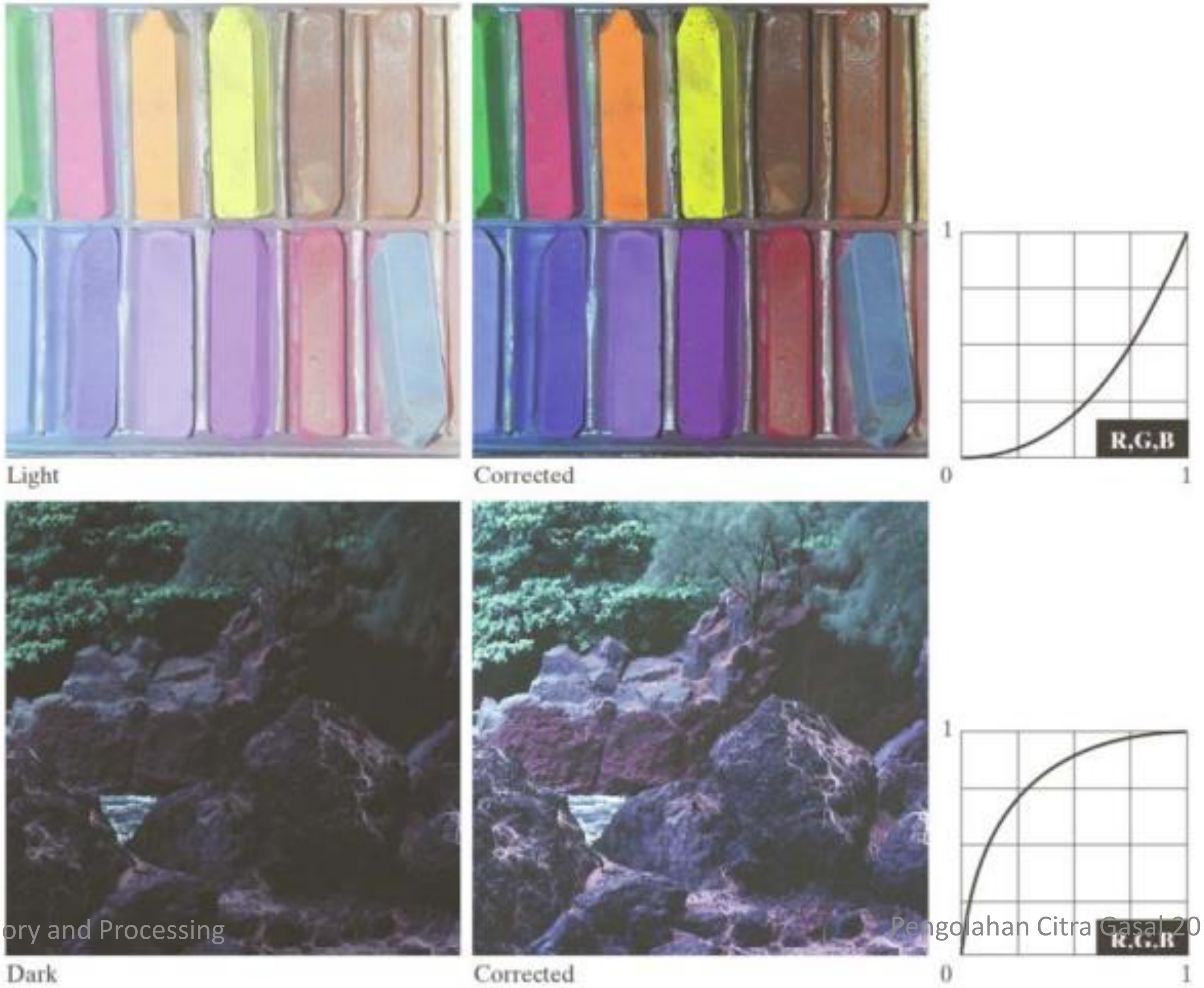


Reds with a radius of 0.2549 from a.



Reds with a radius of 0.1765 from a.

Color Correction

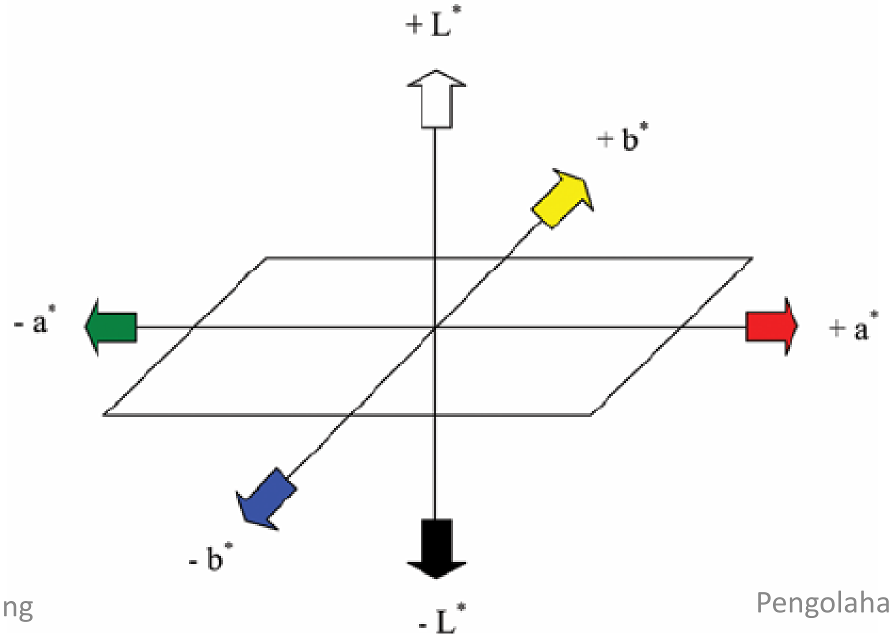


Color Correction (2)

- Most common usage:
  - Photo enhancement
  - Color reproduction (across devices)
- Subjective
  - Attempting to obtain the most *visually pleasing* color image.
- To create neutrality, use a **device-independent color model**
  - The model of choice is commonly CIELAB*

CIELAB

- The nonlinear relations for *L**, *a**, and *b** are intended to mimic the nonlinear response of the eye.
- Components L, a*, b*
  - ***L**** for the lightness
  - ***a**** and ***b**** for the green–red and blue–yellow color components.



CIELAB (2)

- CIELAB Conversion

$$L^* = 116. f\left(\frac{Y}{Y_W}\right) - 16$$

$$a^* = 500\left[f\left(\frac{X}{X_W}\right) - f\left(\frac{Y}{Y_W}\right)\right]$$

$$b^* = 200\left[f\left(\frac{Y}{Y_W}\right) - f\left(\frac{Z}{Z_W}\right)\right]$$

  - Where XYZ are ....
  - X_W, Y_W, Z_W are...............
  - $f(q) = \begin{cases} \sqrt[3]{q}, & if\ q > 0.008856 \\ 7.787q + \frac{16}{116}, & if\ q \leq 0.008856 \end{cases}$

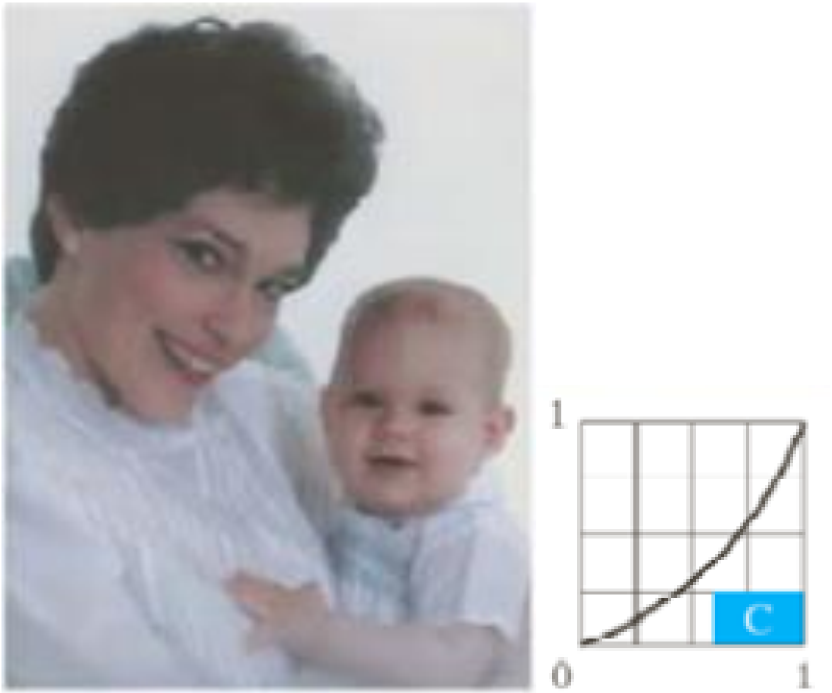
Color Balancing

- For a **visually pleasing image** for human vision, we desire a balance between color components
  - Depending on the color model used
- **Very subjective**
- Arbitrary corrections based on human visual judgement
  - Log transformations
  - Color transformations
  - Manual transformations

Color Balancing

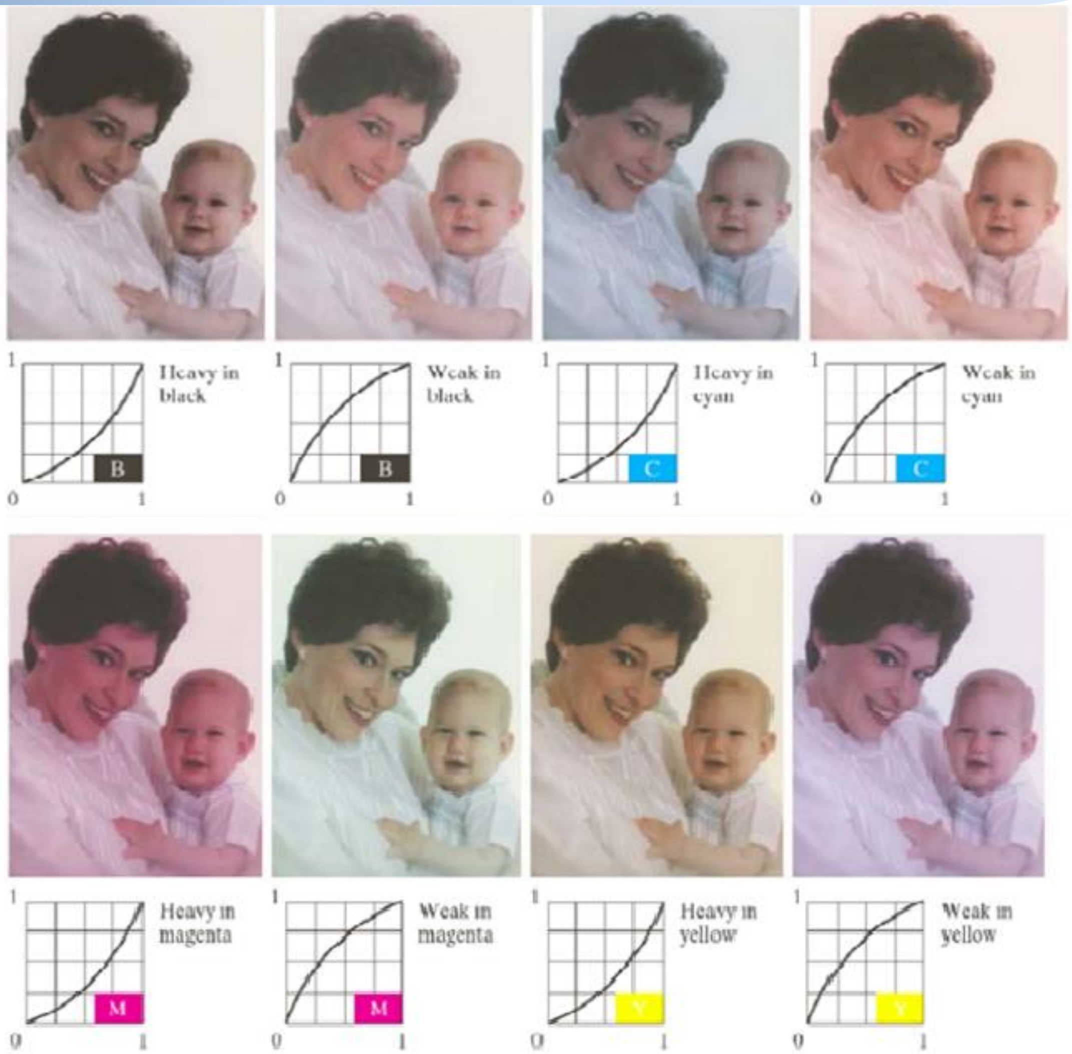
- Assume the CMYK color model

Original



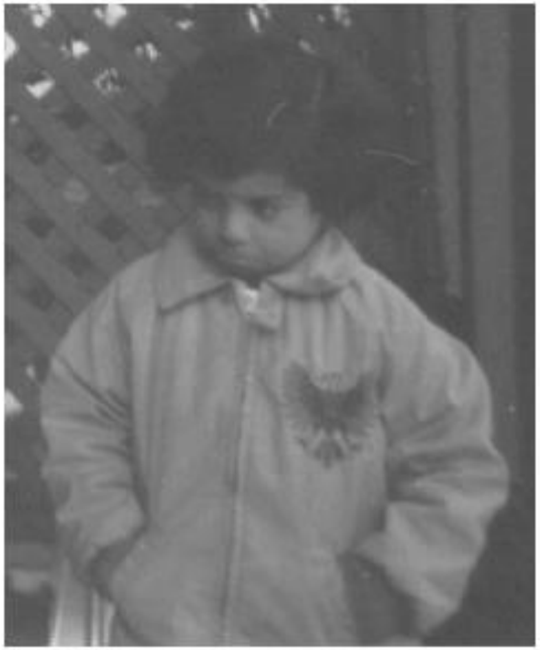
Heavy in Cyan

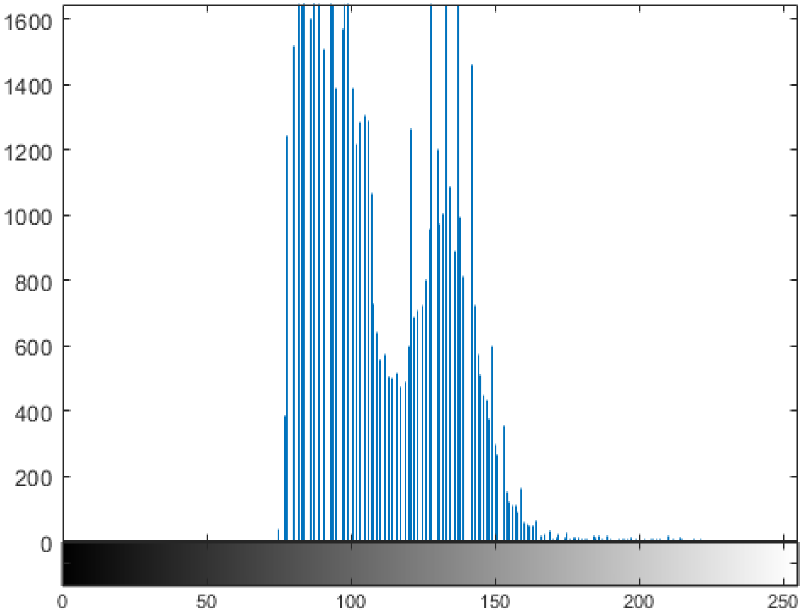
Color Balancing in CMYK



Histogram Processing

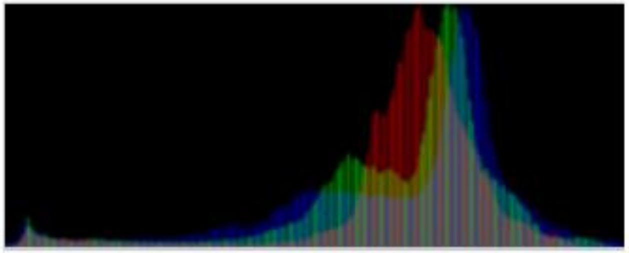
- Recall: What is a histogram? What does it show?
- The histogram plots the distribution of intensity values throughout the image





Color Histogram Processing

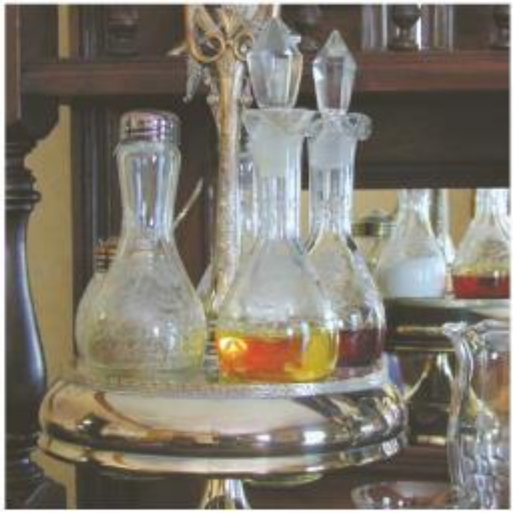
- If we have various channels, create histograms for each

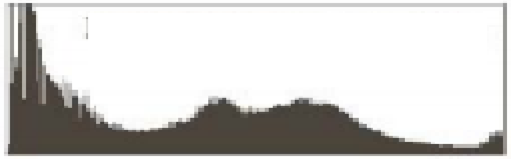


- For RGB space: R histogram, G histogram, B histogram
  - How to use this as a feature?
  - Plus / minuses?

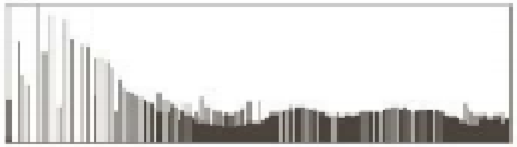
Histogram Equalization

- For color images, HSI's intensity channel I is particularly suited for this process

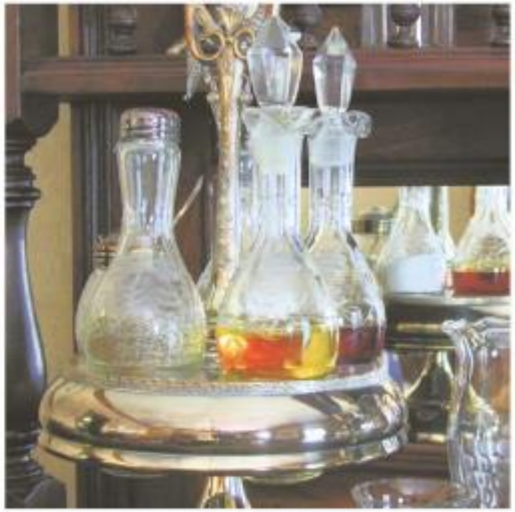




Histogram of I before



Histogram of I after



- Usually followed up with saturation correction

Recall

- Image Enhancement → Color Enhancement?
  - Smoothing and Sharpening

Smoothing

- Why?

- Color Image Smoothing $\bar{\boldsymbol{c}}(x,y) = \frac{1}{K} \sum_{(s,t)\in S_{xy}} \boldsymbol{c}(s,t)$

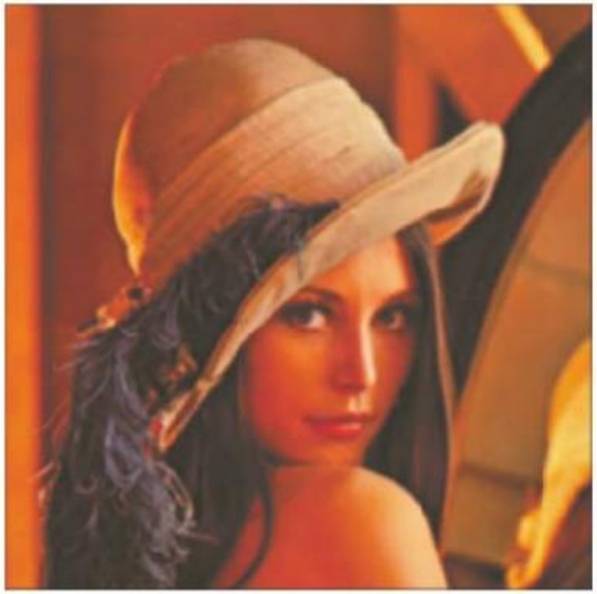
$$\bar{\boldsymbol{c}}(x,y) = \begin{bmatrix} \frac{1}{K} \sum_{(s,t)\in S_{xy}} \boldsymbol{R}(s,t) \\ \frac{1}{K} \sum_{(s,t)\in S_{xy}} \boldsymbol{G}(s,t) \\ \frac{1}{K} \sum_{(s,t)\in S_{xy}} \boldsymbol{B}(s,t) \end{bmatrix}$$

Smoothing (2)

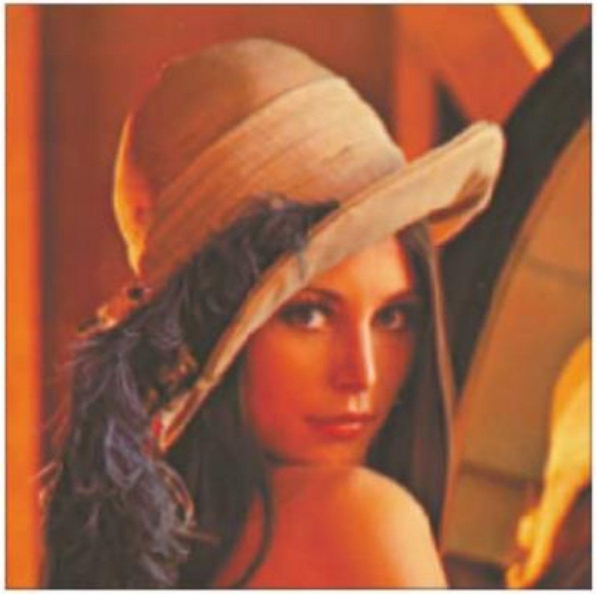
- 2 approaches based on RGB / HSI color spaces
- RGB
  - Smoothing on each channel
  - Join back into new R’G’B’ image
- HSI
  - Smoothing on I channel only

- What differences will happen?

Smoothing (3)



Smoothing RGB



Smoothing HSI

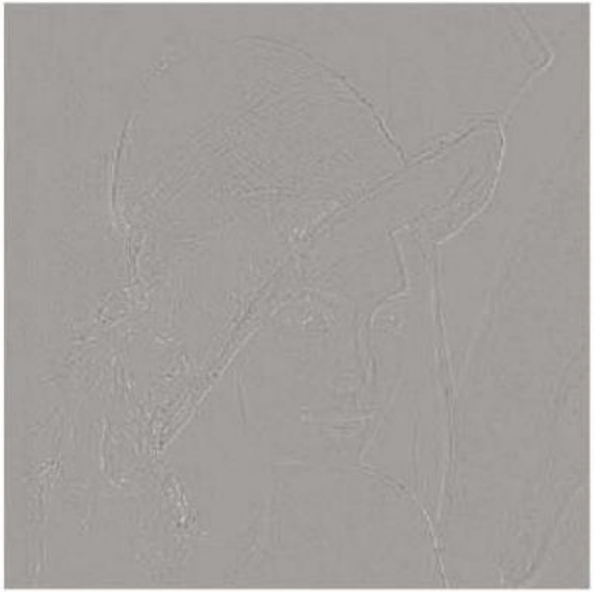


Image Difference

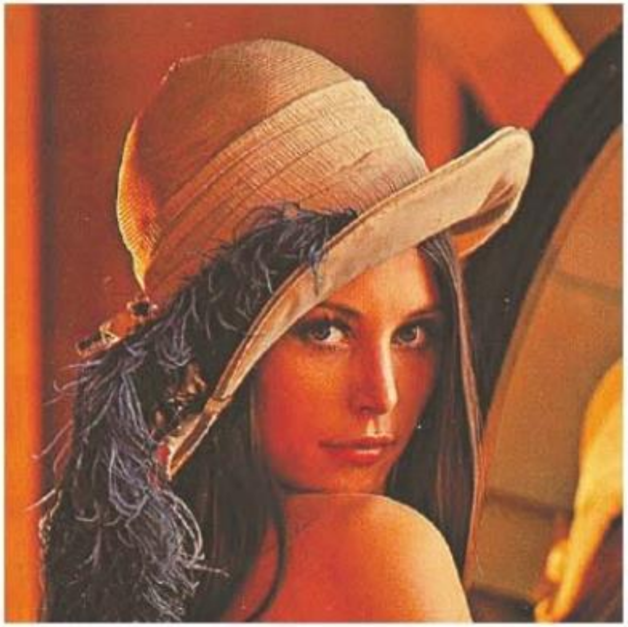
Sharpening

- Why?
- Color Image Sharpening

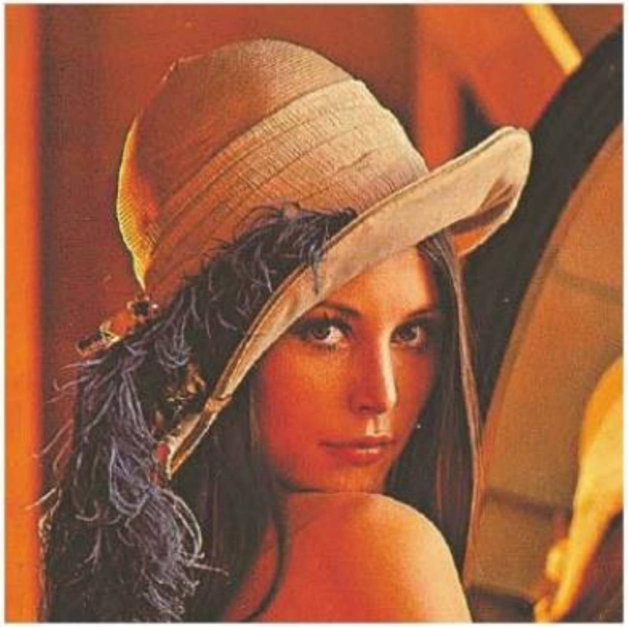
$$\nabla^2[\mathbf{c}(x,y)] = \begin{bmatrix} \nabla^2[R(x,y)] \\ \nabla^2[G(x,y)] \\ \nabla^2[B(x,y)] \end{bmatrix}$$

  - Based on the Laplacian operator (recall grayscale operations)
- Processing methods
  - RGB
  - HSI

Sharpening (2)



Sharpening RGB



Sharpening HSI

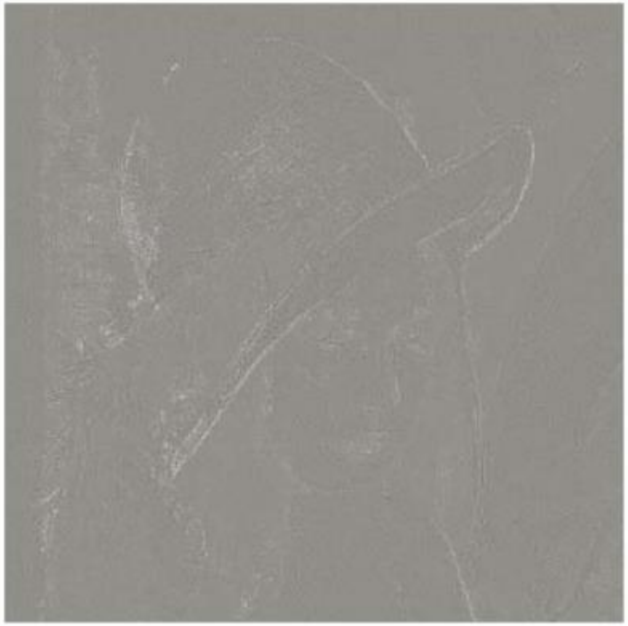
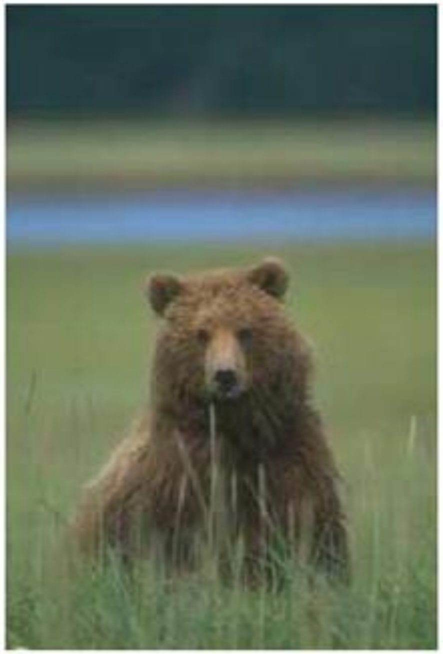


Image Difference

Color Image Segmentation

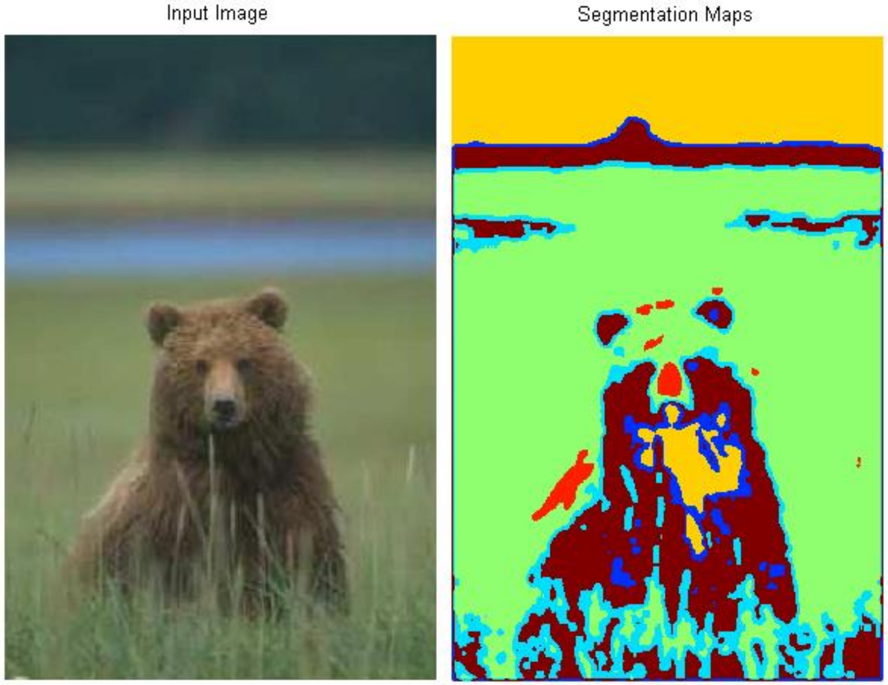
- Ada “segmen” apa saja pada citra di bawah ini?



Input Image

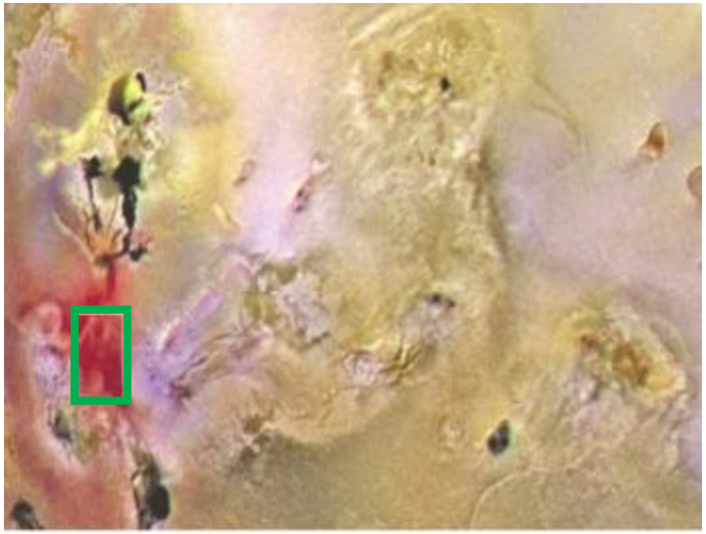
Color Image Segmentation

- Jika kita ingin mempartisi citra berdasarkan warnanya, maka kita dapat melakukannya pada setiap lapisan warna
- Dapat menggunakan metode thresholding and distance



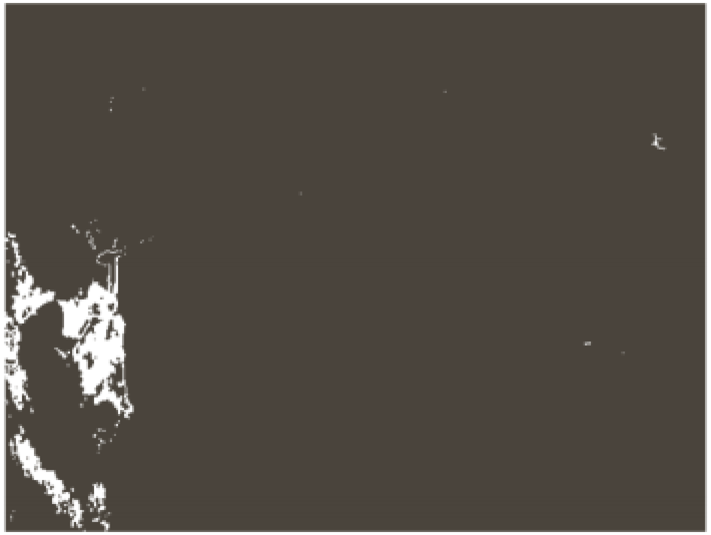
Color Image Segmentation in RGB

- RGB image with color of interest



- Take the mean color value in ROI

- Resulting mask showing the colors “near” to color in ROI



Similar Colors

- What does it mean for 2 colors to be “near” or “similar”?

- For target color **a** and arbitrary color **z**
- **a** and **z** are similar if
    - The distance between them is less then threshold D_0

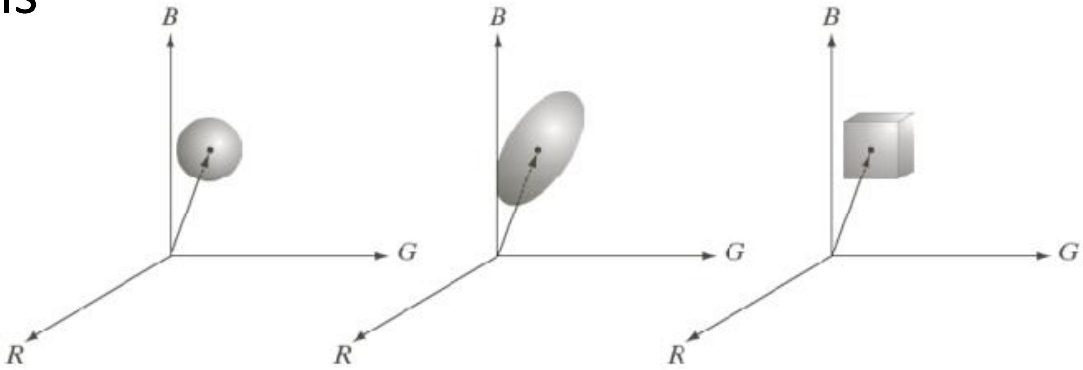
- How to measure it?

Euclidean Distance

- Desired color **a** and arbitrary color **z**

$$D(z,a) = \|\boldsymbol{z} - \boldsymbol{a}\|$$
$$= \sqrt{\|(\boldsymbol{z} - \boldsymbol{a})^T(\boldsymbol{z} - \boldsymbol{a})\|}$$
$$= \sqrt{(z_R - a_R)^2 + (z_G - a_G)^2 + (z_B - a_B)^2}$$

- Generalizations



Advantages / disadvantages of Euclidean Distance?

CIELAB Colour Difference

- Remember CIELAB?
  - The nonlinear relations for *L**, *a**, and *b** are intended to mimic the nonlinear response of the eye.
  - CIELAB describes color differences for the human visual system

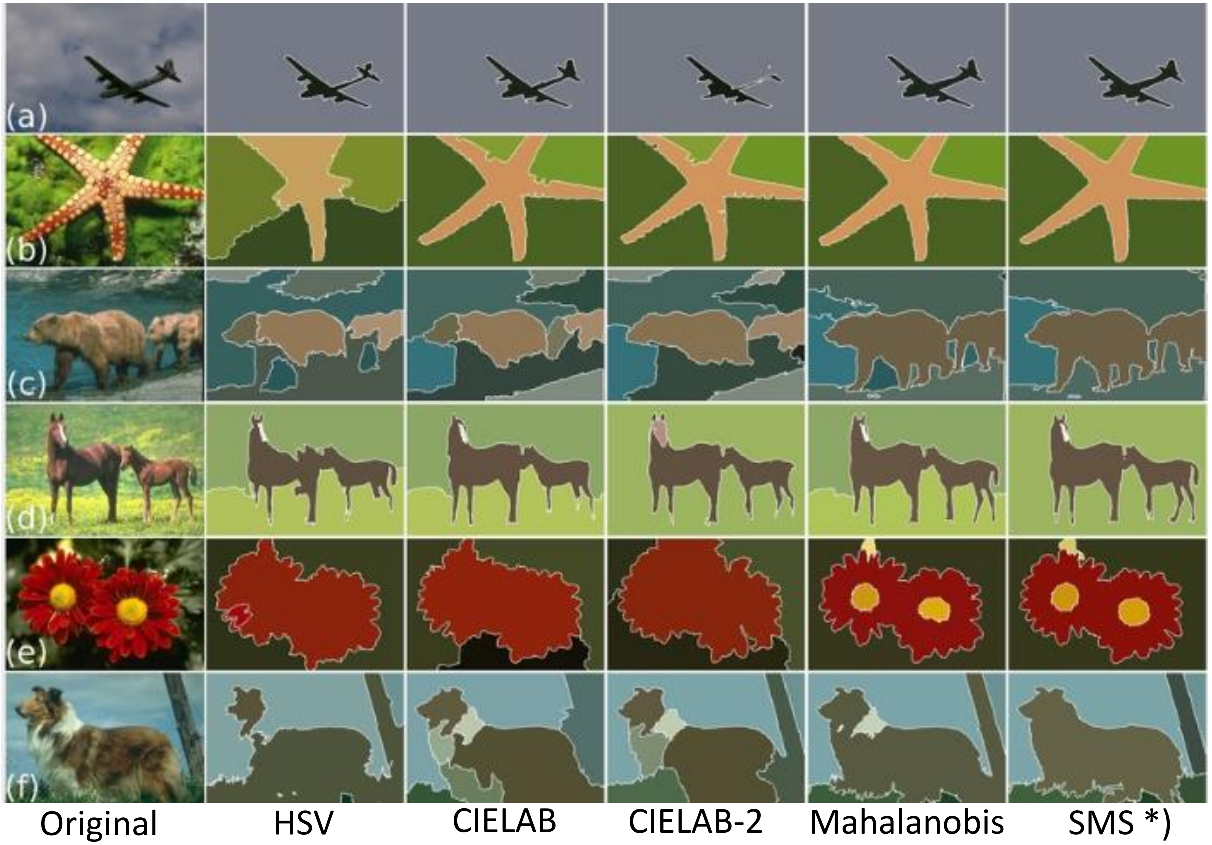
$$\Delta E^{*}_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where

$$\Delta L^* = L^*_2 - L^*_1, \quad \Delta a^* = a^*_2 - a^*_1, \quad \Delta b^* = b^*_2 - b^*_1$$

Color Image Segmentation

- Highly dependent on color space and distance measure



*) Sobieranski, A. C., Comunello, E., & von Wangenheim, A. (2011). Learning a nonlinear distance metric for supervised region-merging image segmentation. *Computer Vision and Image Understanding*, *115*(2), 127-139.

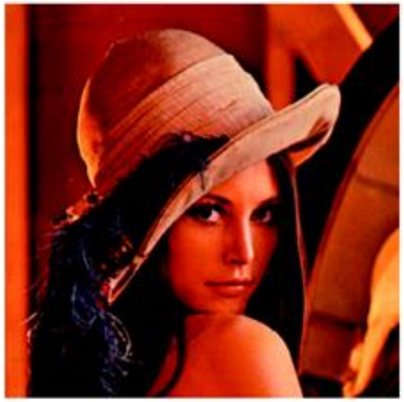
Variations of Color Difference Formulas

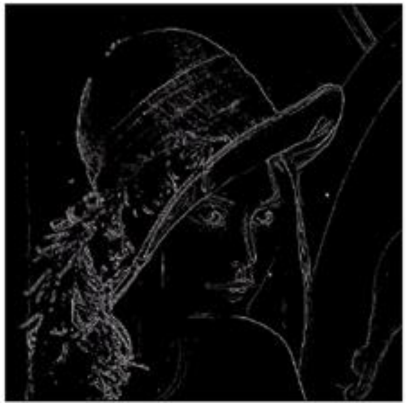
- CIELAB Color difference formula
- CIELUV Color difference formula
- CMC Color difference formula
- CIE94 Color difference formula

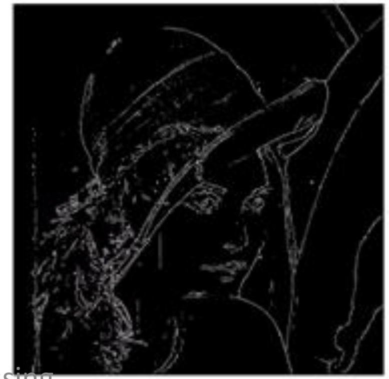
- ..and many more

Edge Detection

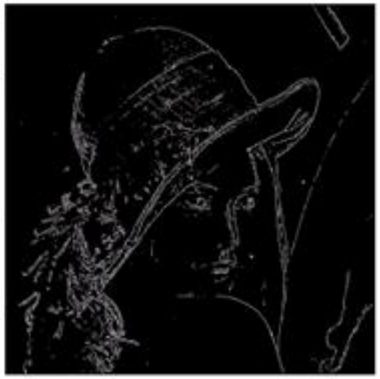
- We used gradients for grayscale images
  - Valid for a scalar function, not vector functions
- Per channel



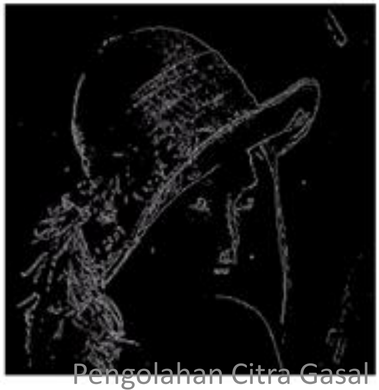




R



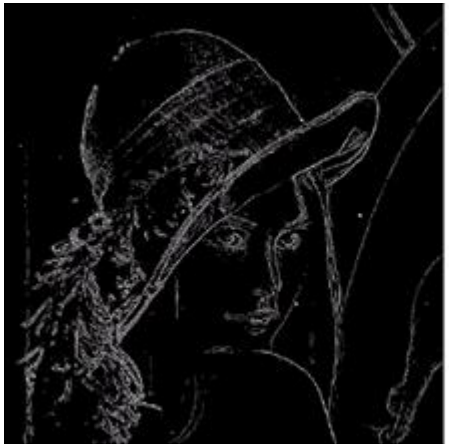
G



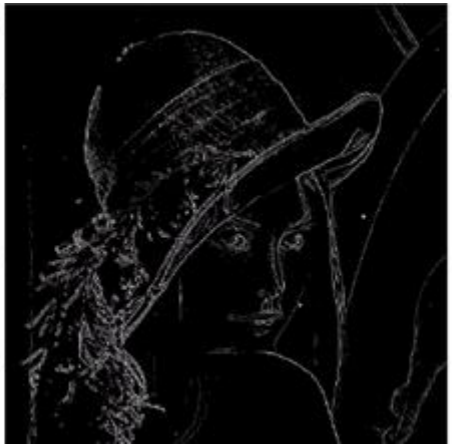
B

Edge Detection (2)

- RGB color vector approach



Color Vector



Per Channel

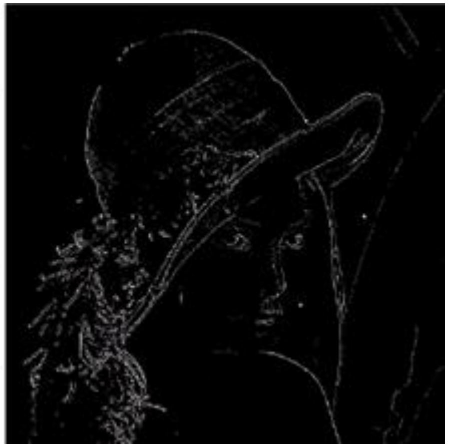


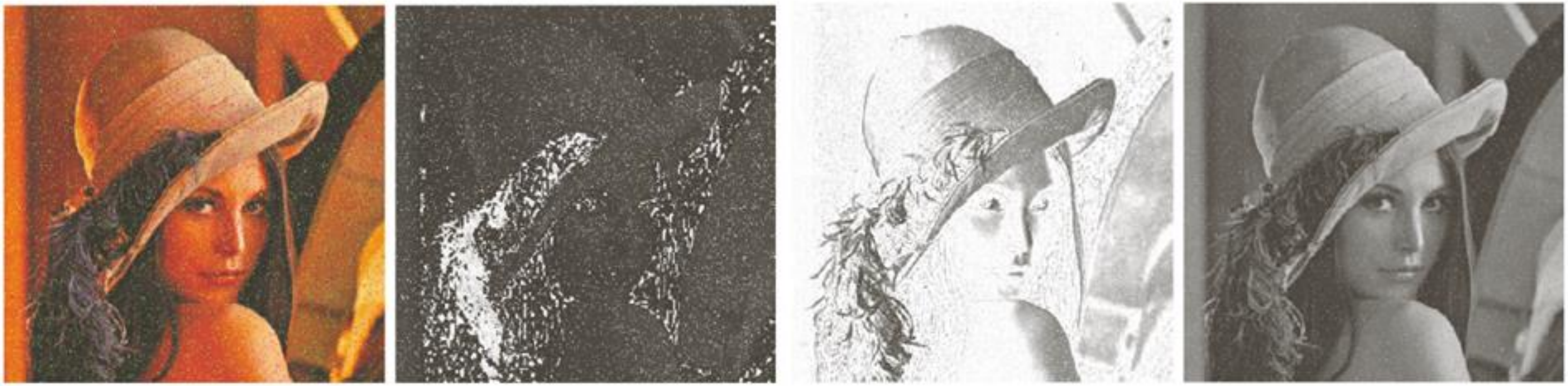
Image Difference

Noise pada Citra Berwarna

- Noise pada setiap layer warna bisa sama, bisa tidak.
- Noise bisa terjadi jika piranti elektronik pada layer tersebut rusak.
- Salah satu cara menghilangkan noise bisa dengan melakukan average filtering atau median filtering

Noise in RGB vs HSI

- Noise in RGB spreads to all channels of HSI



Corrupted G channel