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Color image processing

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Elaborazione delle immagini
(Image processing I)

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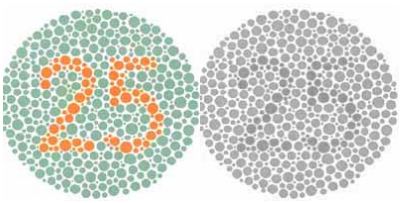
Color images



- Color is a feature that can greatly improve the description of the scene.
- The shades of colors the can be discriminated by the human visual system are much more than the gray ones (thousands vs. dozens).
- The color can be studied as:
  - a physical phenomenon;
  - a perceptive phenomenon.

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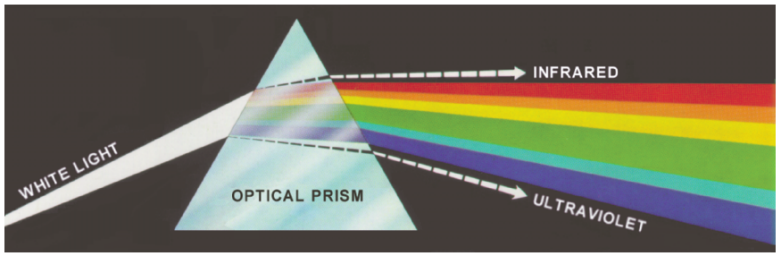
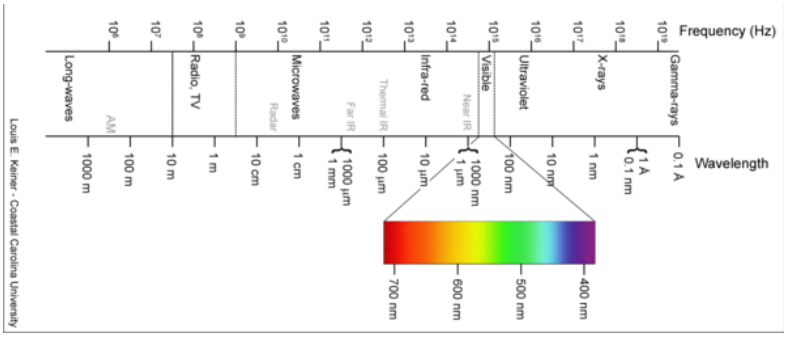
Physical nature of the color

- Structure of the visible light
  - white light decomposition (Isaac Newton, 1666)





Physical nature of the color (2)

- Features of a light source:
  - radiance: emitted energy [Watt, W]
    - measured with respect to a particular angle and surface.
  - luminance: perceived energy [lumen, lm]
  - brightness: subjective description (e.g., glare)

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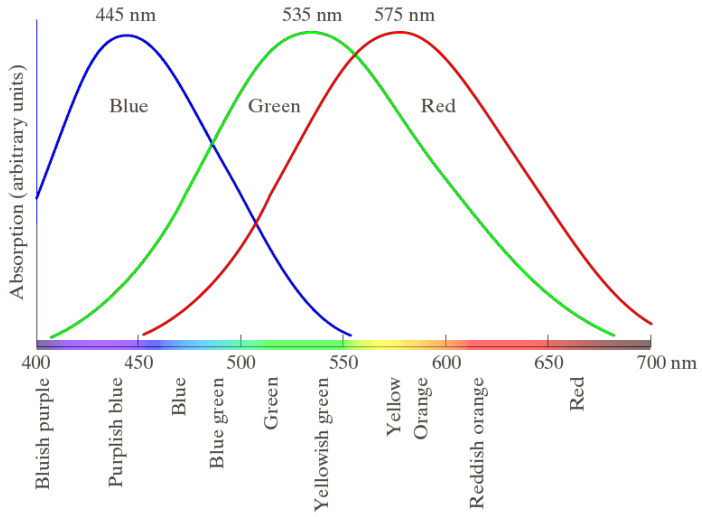
Color perception

- Photopic vision, due to the cones (1965):



- each perceived color results from the activation of the cones belonging to the different types.

Color perception (2)

- CIE primary colors (1931):
  - blue: 435.8 nm
  - green: 546.1 nm
  - red: 700 nm
- arbitrarily established before the experimental evidence of the previous figure;
- primary and secondary colors
  - mixing the primary colors, *most* of the visible colors can be obtained;
  - in particular, the secondary colors.
- emitted light (source) and reflected light (pigment)
  - additive and subtractive composition

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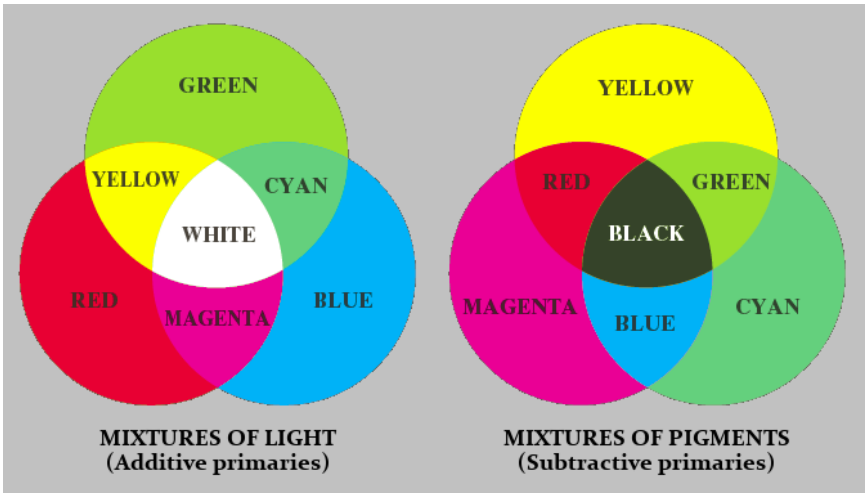
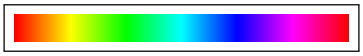
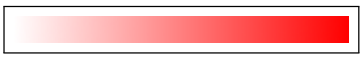
Color perception (3)

- primary (and secondary) colors additive and subtractive:



Color spaces

- Features of the light:
  - luminosity 
    - generalization of the intensity
  - hue 
    - dominant color
  - saturation 
    - color purity, quantity of white (pink is half saturated red)

  hue + saturation = chromaticity

- A color space provide a reference system for measuring the color.

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Color spaces (2)

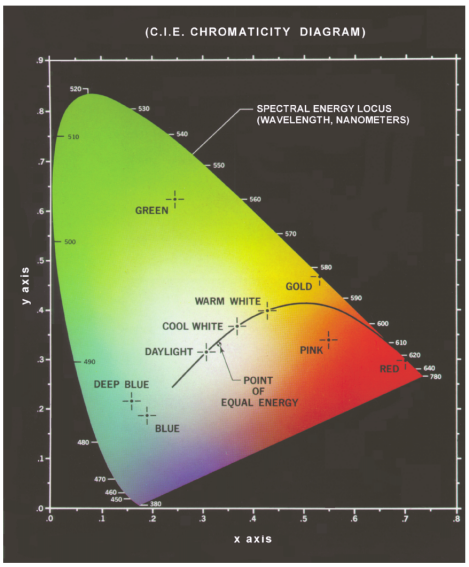
- Tristimulus: color coordinates for intensity value equal to 1.
  - X, Y, Z are color (not visible corresponding to R, G and B stimulii)
  - normalizing:

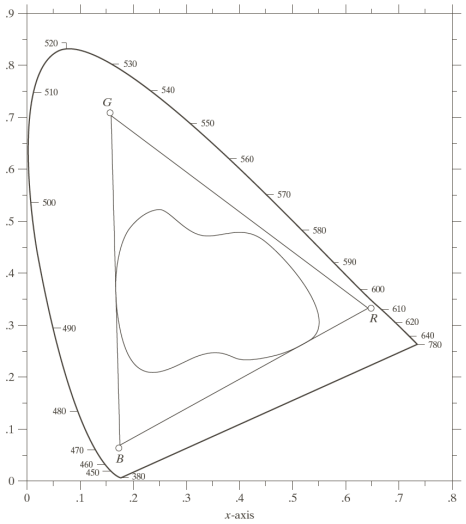
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

- A graph can be traced on the x-y plane and z can be derived as $z = 1 - x - y$.

Color spaces (3)





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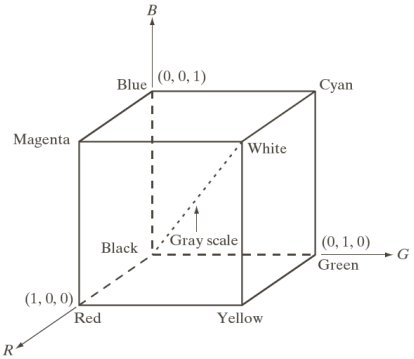
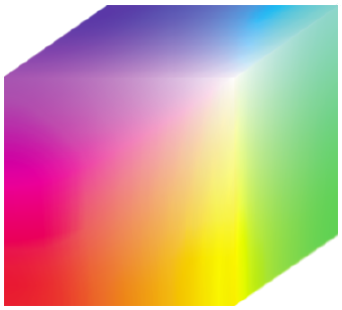
RGB color model

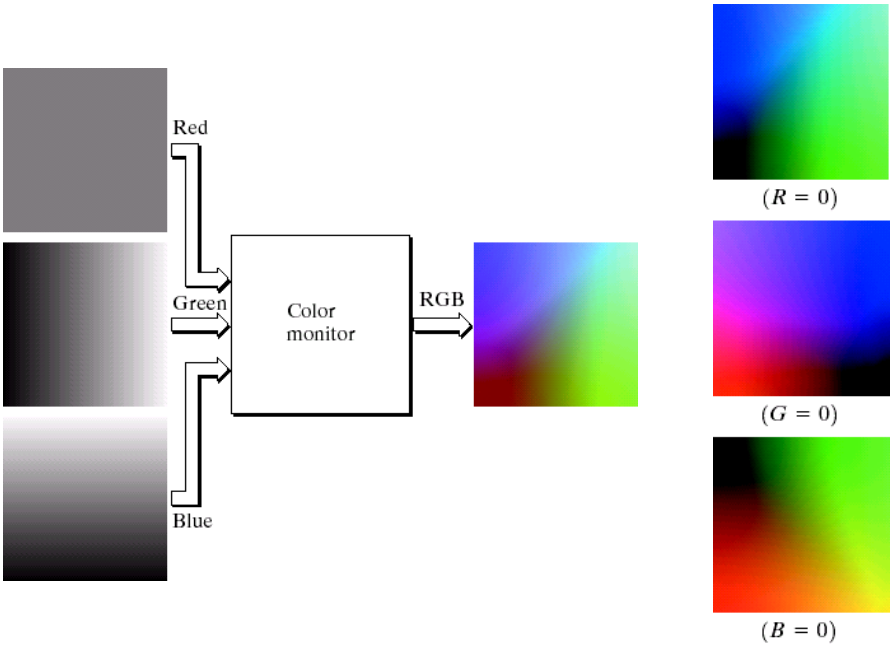
- RGB: cube





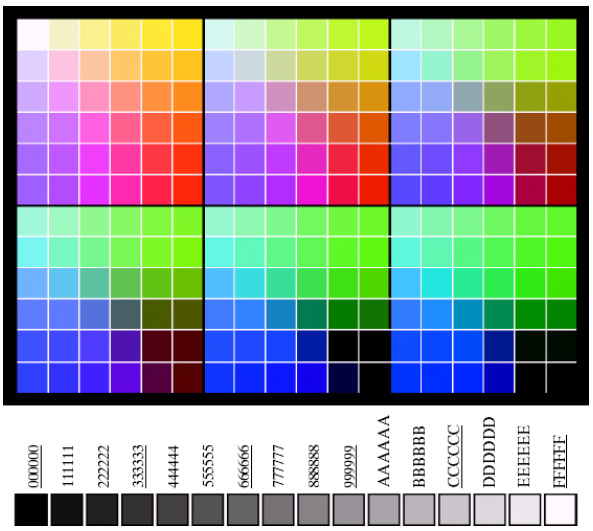
RGB color model (2)

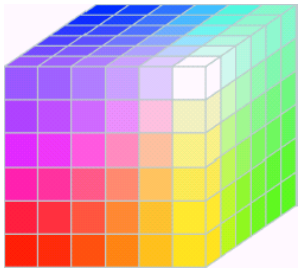
- RGB color formation



RGB color model (3)

- "safe" colors: quantization $6 \times 6 \times 6 = 216$





Other color models

- CMY (CMYK)

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- CIE L*a*b*

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

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

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

where

$$h(q) = \begin{cases} \sqrt[3]{q} & q > 0.008856 \\ 7.787\, q & q \leq 0.008856 \end{cases}$$

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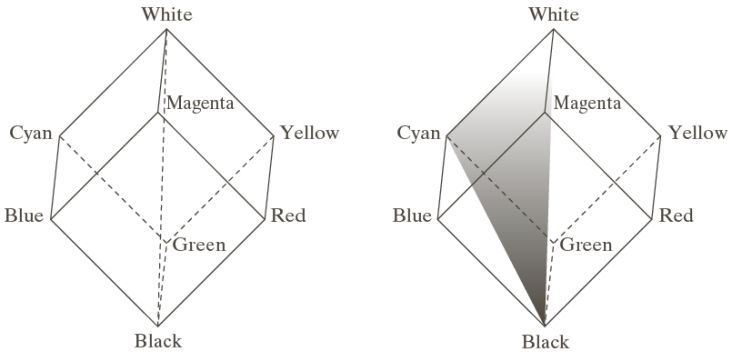
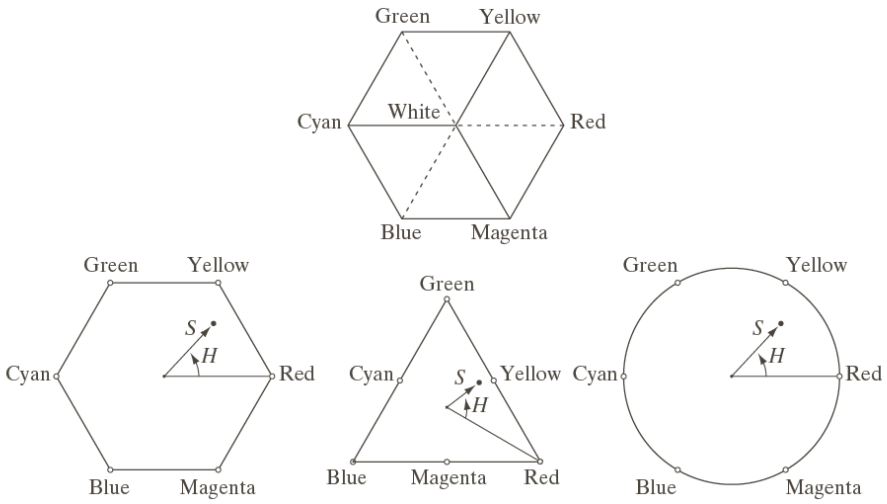
HSI color model

- RGB is useful for colors representation, not for description.
- HSI: (Hue, Saturation, Intensity)
  - HSV: (Hue, Saturation, Value)
- Hue: dominant color
- Saturation: distance from white
- Intensity: distance from black
- HSI fits better to the human perception of the color sensation.



HSI color model (2)



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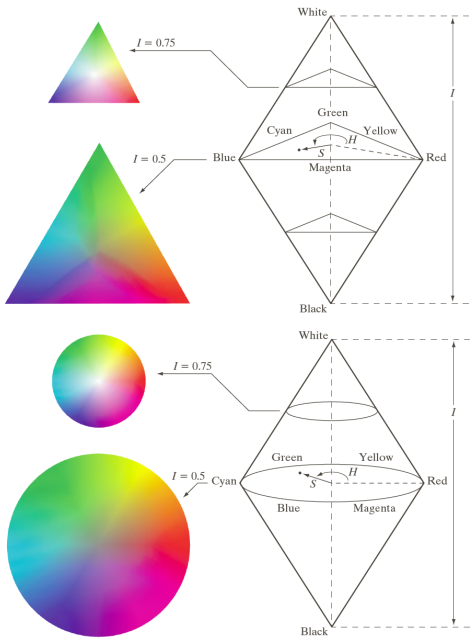
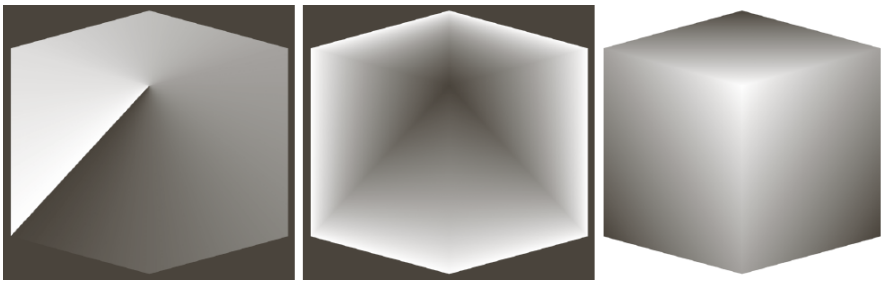
HSI color model (3)



RGB to/from HSI conversion

- RGB from/to HSI conversion formulas can be derived from the geometric relations between the two spaces.
- However, it should be noticed that:
  - hue is an angle with respect to the red position;
    - it can be normalized by dividing its value for the round angle;
    - red has hue value of both 0 and 1.
  - white and black are identified only by the intensity value.



RGB cube represented in the HSI space.

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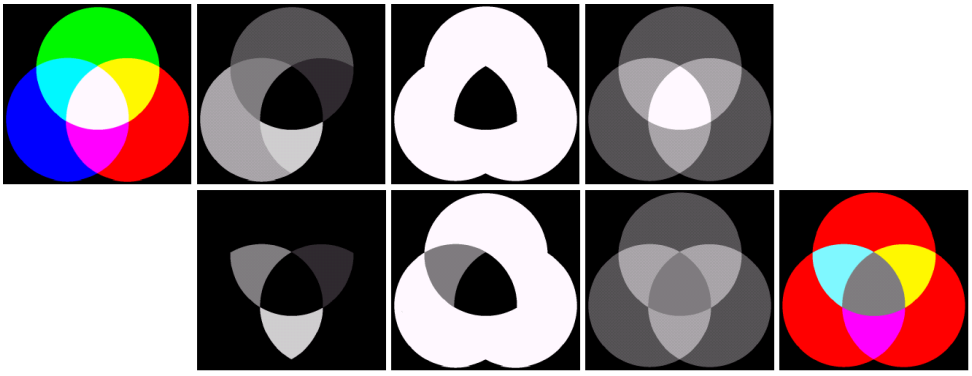
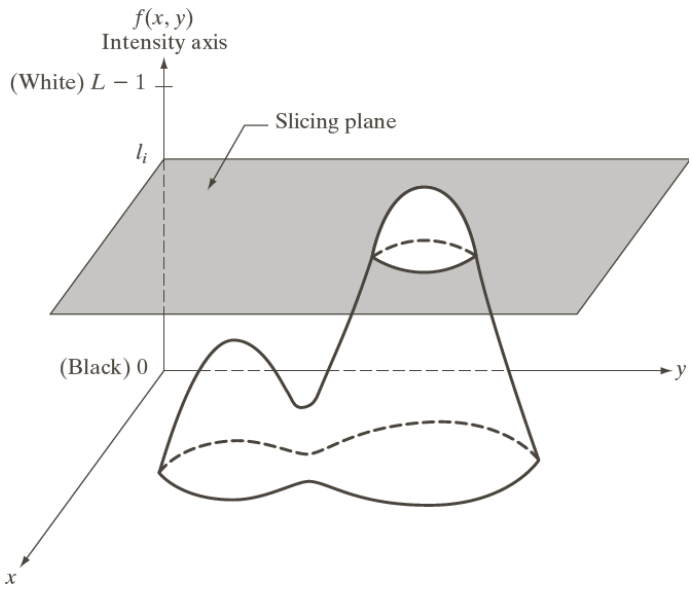
HSI processing example

- Processing can be more easy in HSI space, since its effects are more predictable in terms of color modification.



Intensity slicing

- Pseudocolor processing consists in assigning different color to different intensity ranges.



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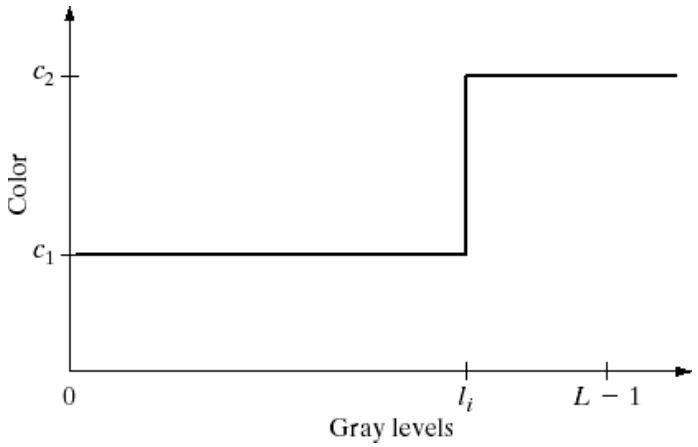
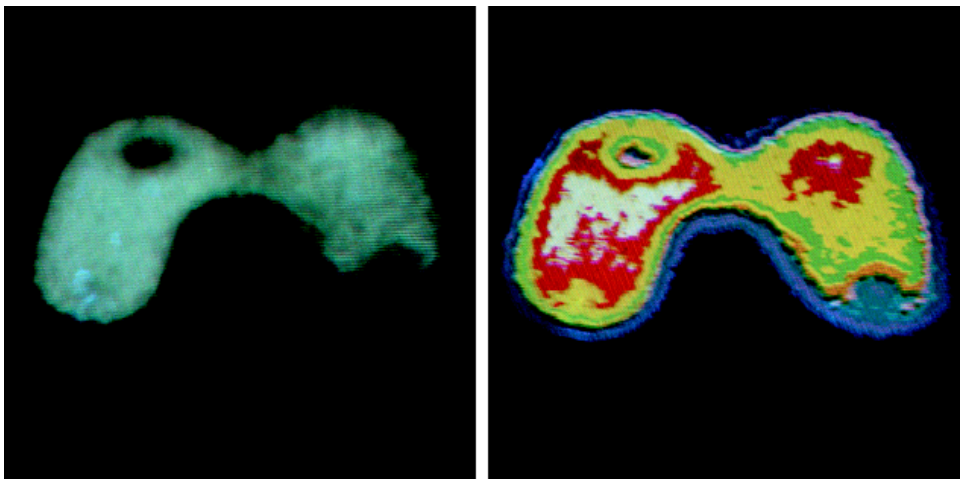
Intensity slicing (2)



Intensity slicing (3)



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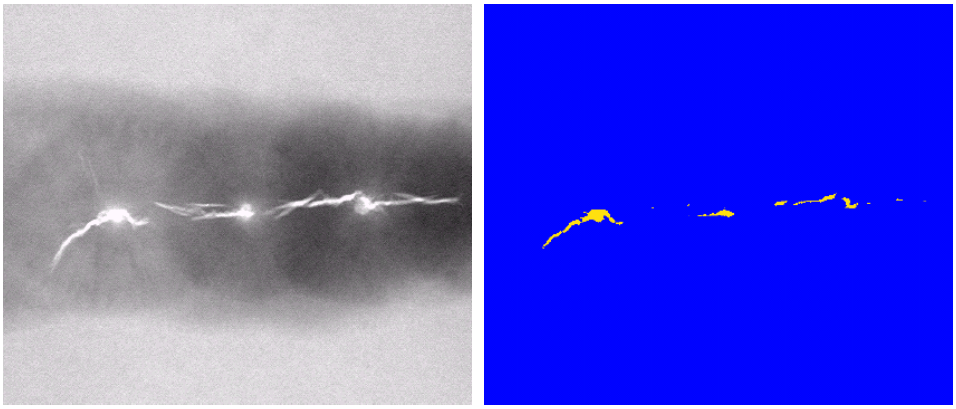
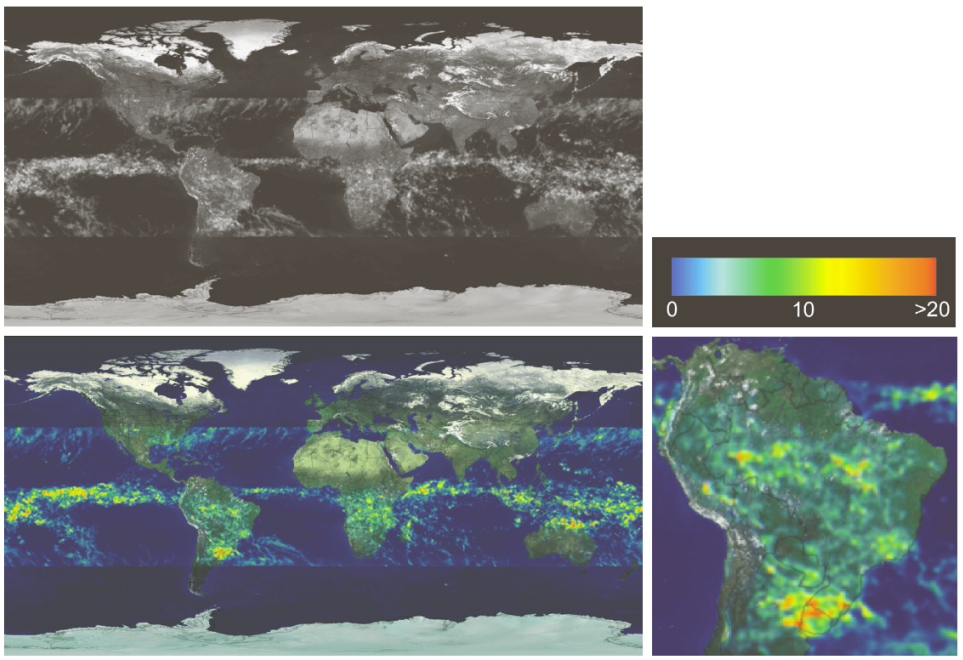
Intensity slicing (4)



Intensity slicing (5)



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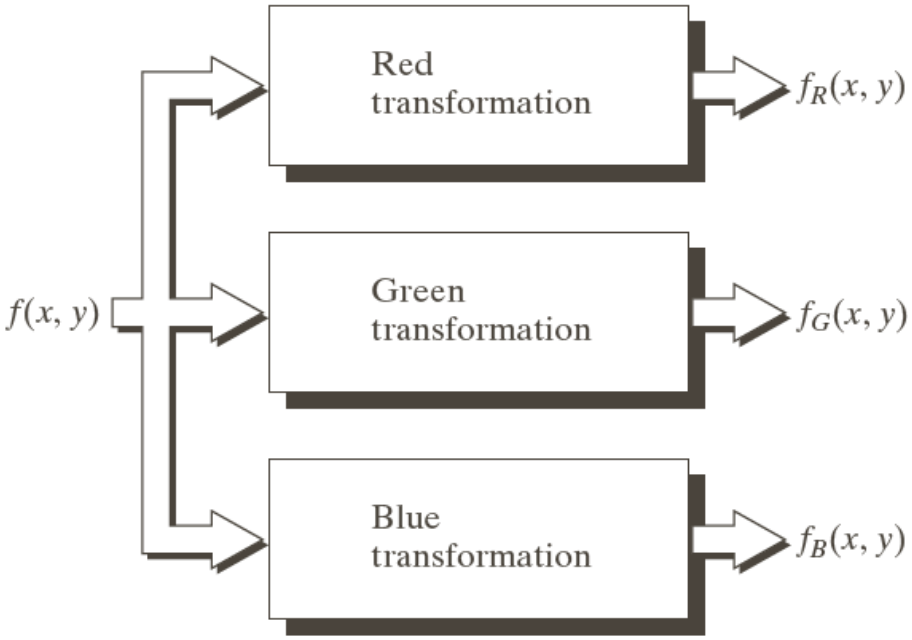
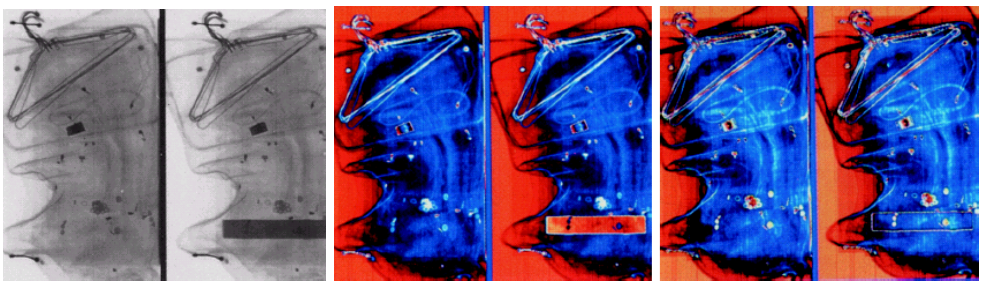
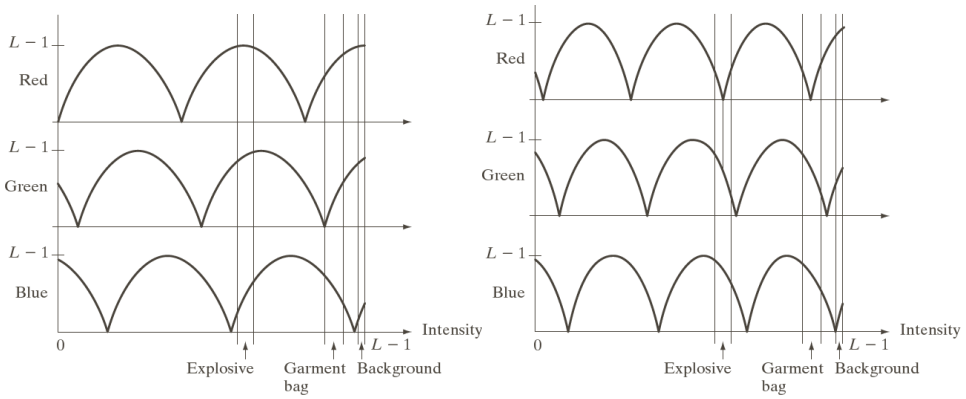
Intensity to color transformations



Intensity to color transformation (2)





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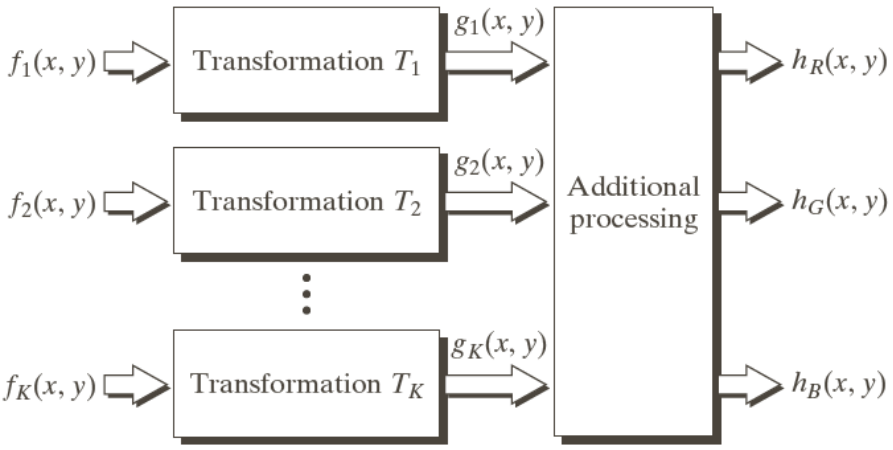
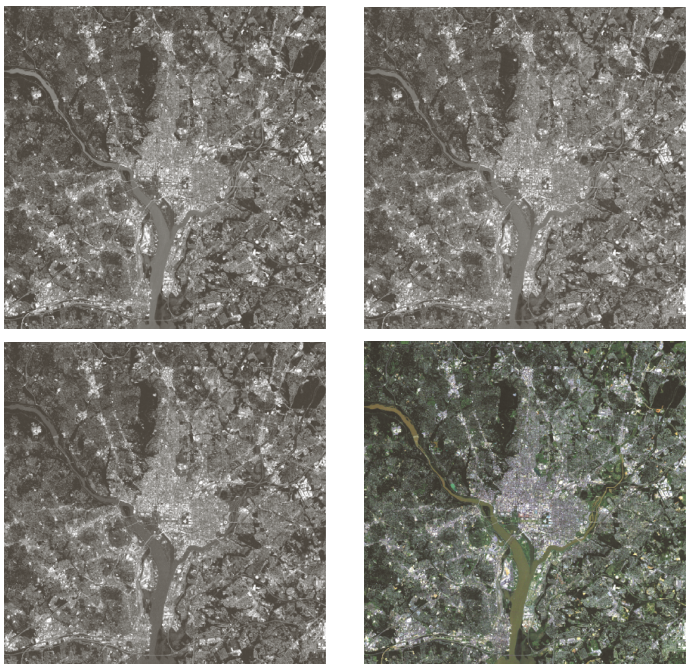
Intensity to color transformation (3)



Intensity to color transformation (4)



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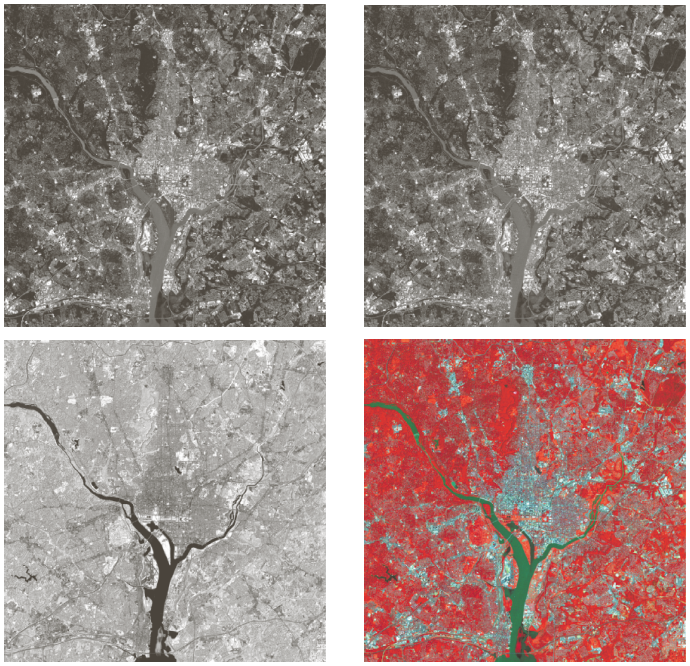
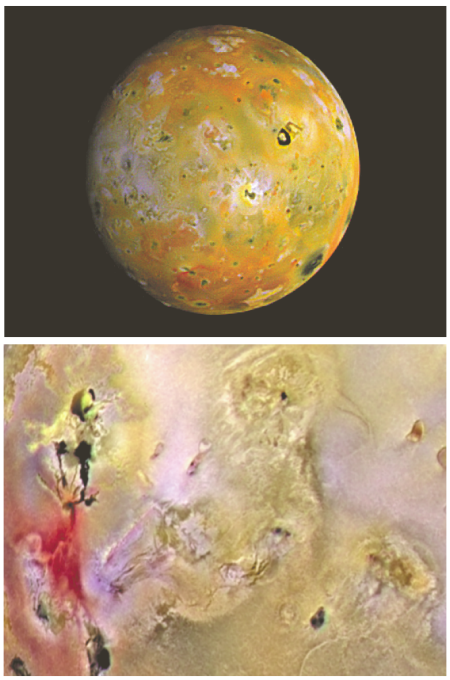
Intensity to color transformation (5)



Intensity to color transformation (6)



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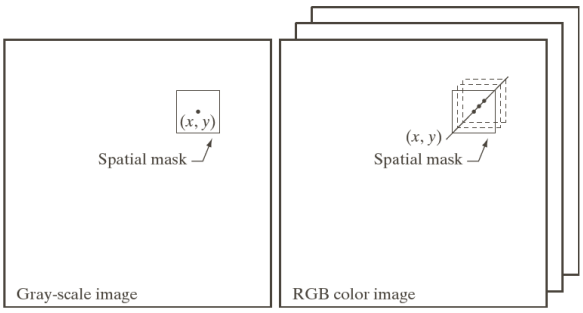
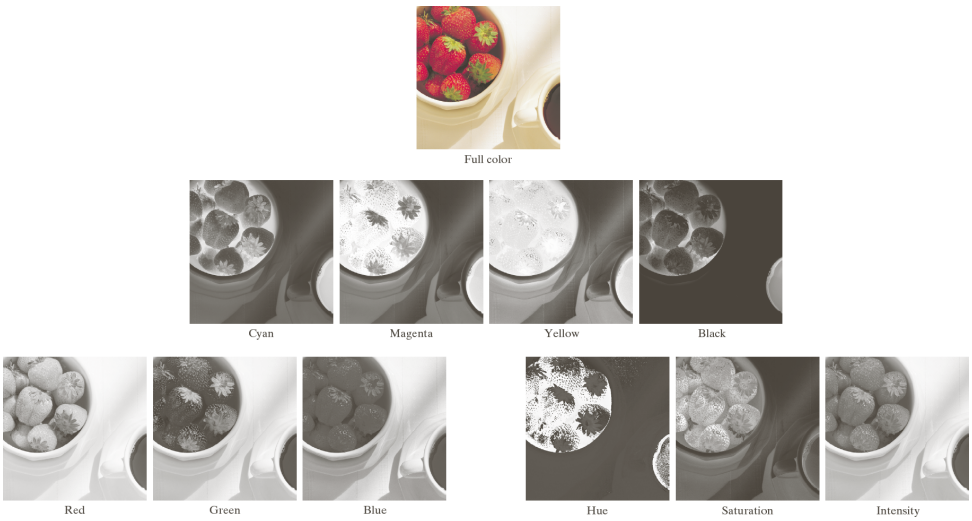
Color image processing

- The concept of spatial mask can be generalized for color images.



Representation in different color spaces



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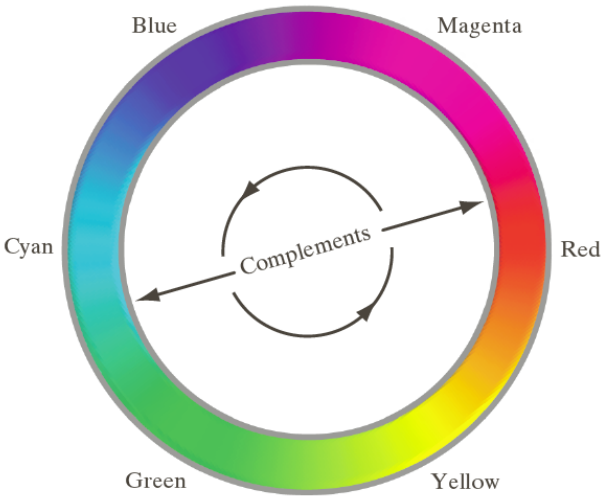
Intensity adjustment

- The same processing can be operated in different color spaces.

Complement



- Complement is the generalization of the negative intensity transformation.

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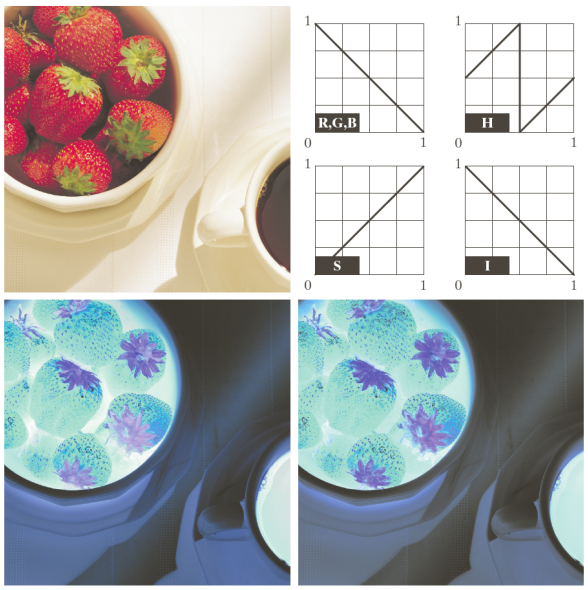
Complement (2)



- Complement can be obtained both in RGB and HSI space.
  - Although in RGB it is more simply expressed.

Tonal correction

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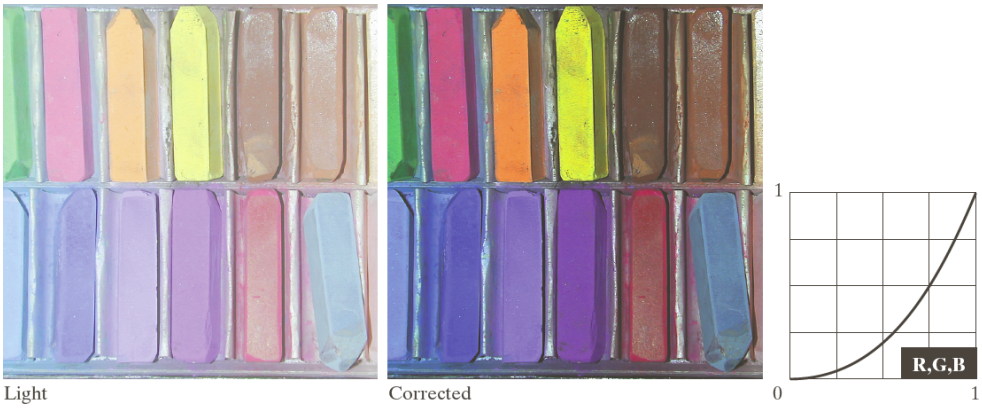
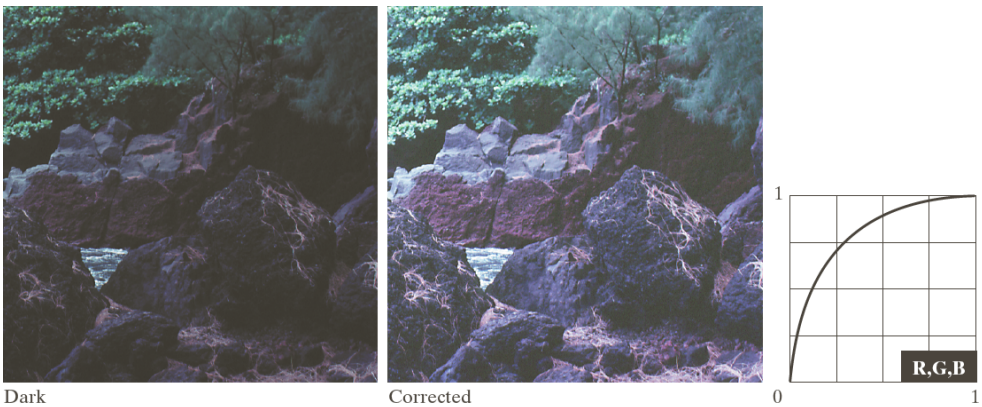
Tonal correction (2)



Light Corrected

Tonal correction (3)



Dark Corrected

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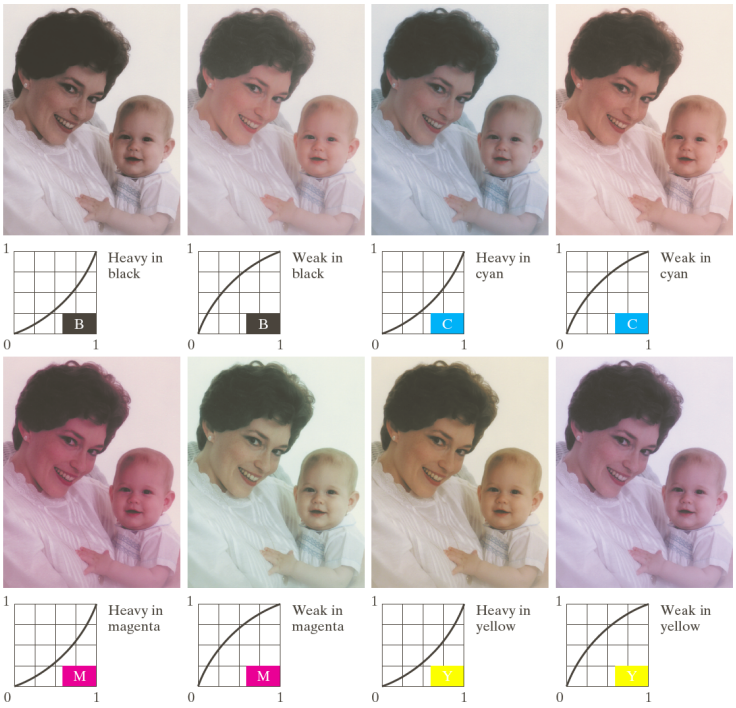
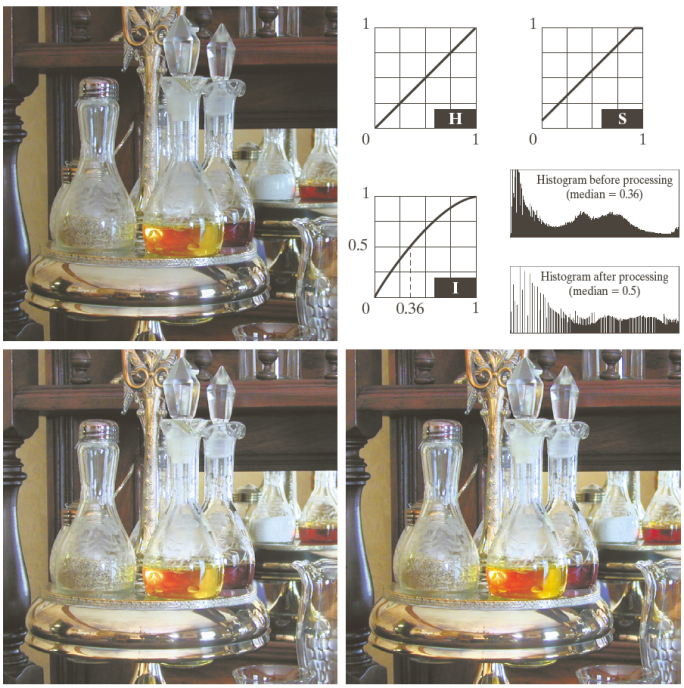
Color balancing correction

Original/Corrected



Histogram equalization



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Lena

Smoothing

a | b | c

(a) 5×5 smoothing applied to all the RGB channels.
(b) 5×5 smoothing applied to the intensity channel.
(c) Difference.

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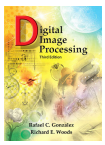
Laplacian

a | b | c

(a) Laplacian sharpening applied to all the RGB channels.
(b) Laplacian sharpening applied to the intensity channel.
(c) Difference.

Homeworks and suggested readings



DIP, Sections 6.1–6.6

- pp. 394–443

GIMP

- Colors
  - Hue-Saturation
  - Brightness-Contrast
  - Threshold
  - Levels
  - Curves
  - Invert
  - Auto

Lena story

- `http://en.wikipedia.org/wiki/Lenna`
- `http://www.ee.cityu.edu.hk/~lmpo/lenna/Lenna97.html`