Connected Components Labeling

- Segmentation

Recursive Labeling Algorithm

- Let $I$ denote the image.
- Step 1: Convert $I$ to $B$.
- Step 2: Let $B' = -B$, label = 0
1. for $i = 1$:rows
2. for $j = 1$:columns
3. if $B'(i,j) == -1$
4. label = label + 1;
5. Add $(i,j)$ onto Stack and set $B'(i,j) = label$;
6.
7. while (Stack is not empty)
8. Remove pixel $P$ from Stack
9. Let $M = $ neighbors of $P$ whose pixel value = -1;
10. Add $M$ onto Stack;
11. Set $B'(M) = label$;
12. end
13. end
14. end

A Simple Example

- Given

More Complicated Examples
Color

- Different wavelengths/frequencies of EM radiation correspond to different colors
- Different light sources have different spectral characteristics
  - Incandescent
  - Fluorescent
  - Natural light (i.e. sun)

The Physics

Examples of the Reflectance Spectra of Surfaces

% Photons Reflected

Illumination

Perception

Reflectance

Wavelength (nm)
Psychophysics of Color

• We don’t see color in EM waves
• The perceptual meaning of color

Psychophysics of Color

There is no simple functional description for the perceived color of all lights under all viewing conditions, but ... 

A helpful constraint: Consider only physical spectra with normal distributions

Psychophysics of Color

Mean ↔ Hue

# Photons

Wavelength

Psychophysics of Color

Variance ↔ Saturation

# Photons

Wavelength
Quantitative Measure of Color

- We have to make some assumption for the color we will see in our environment.
- Assumption:
  - All color can be mixed from 3 primary colors => can describe any color using 3 numbers.
  - These 3 colors lead to different color spaces.

Additive and Subtractive Color

See Wikipedia: Additive & Subtractive Color.
Grassmann's Law

- Trichromacy in human perception

\[ Ta = W_a P_1 + W_2 P_2 + W_3 P_3 \]
\[ Tb = W_b P_1 + W_2 P_2 + W_3 P_3 \]
\[ Ta + Tb = (W_a + W_b) P_1 + (W_2 + W_2) P_2 + (W_3 + W_3) P_3 \]

Physiology of Color Vision

Color Component Theory: Human Color Space

- The black-white or achromatic channel sums signals from R, G and B cones.
  \[ A = R + G + B \]
- The red-green color-opponent channel is excited by signals from the R cones and inhibited by signals from G cones.
  \[ RG = R - G \]
- The blue-yellow color-component channel is excited by signals from B cones and is inhibited by a combination of signals from R and G cones.
  \[ Y = R + G; BY = B - (R + G) \]

Color Space 1: RGB Color Space

- RGB Cube
  - Easy for devices
  - But not perceptual
  - Where do the grays live?
  - Where is hue and saturation?
Color Space 2: HSV (Hue-Saturation-Value)

- Hue, Saturation, Value (Intensity)
  - RGB cube on its vertex
- Decouples the 3 components (a bit)
- How do you convert from one to the other?
  - Wikipedia
  - Use rgb2hsv() and hsv2rgb() in Matlab

Color Space 2: CMY and Black

- For painting, R, Y and B – primary color
- Color pigments are mixed subtractively
- In printing, CMY is used
  - Cyan (blue-green color)
  - Magenta (purplish color)
  - Yellow
- CMY can be seen as negative RGB
  - Cyan = W-R
  - Magenta = W-G
  - Yellow = W-B
- Example: Mix cyan and magenta to get
  - \((W-R) + (W-G) = R+G+B – R – G = B\) (Blue)

CIE RGB Space

1) W. David Wright (Wright 1928) and John Guild (Guild 1931) discovered human CIE RGB space
2) Using 3 primary matching lights, they discovered human rgb response curve
3) CIE XYZ is a linear transformation of this space
**Color Similarity in Different Color Spaces**

- **CIE XYZ**

  \[ (x,y) = \frac{X}{X+Y+Z}, \quad Y/(X+Y+Z) \]

- **CIE LAB**

  \[
  \begin{align*}
  X &= \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \end{bmatrix} G \\
  Y &= \frac{1}{b_{31}} \begin{bmatrix} b_{21} & b_{22} & b_{23} \end{bmatrix} G \\
  Z &= \frac{1}{b_{33}} \begin{bmatrix} b_{31} & b_{32} & b_{33} \end{bmatrix} G
  \end{align*}
  \]

  \[
  \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.17697 \\ 0.70530 \\ 0.12382 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}
  \]

**Color Space 4: CIE LAB Space**

- **CIE XYZ**

  \[ (x,y) = \frac{X}{X+Y+Z}, \quad Y/(X+Y+Z) \]

- **CIE LAB**

  \[
  \begin{align*}
  L &= 116(Y/Yn)^{1/3} - 16; \\
  A &= 500[(X/Xn)^{1/3} - (Y/Yn)^{1/3}] \\
  B &= 200[(Y/Yn)^{1/3} - (Z/Zn)^{1/3}]
  \end{align*}
  \]

- Difference in this space is more close to human color space
**Color Space 5: YUV**

- transform RGB to YCbCr, or to YUV using $3 \times 3$ matrix

\[
\begin{bmatrix}
Y \\
Cb \\
Cr
\end{bmatrix} =
\begin{bmatrix}
\alpha_{11} & \alpha_{12} & \alpha_{13} \\
\alpha_{21} & \alpha_{22} & \alpha_{23} \\
\alpha_{31} & \alpha_{32} & \alpha_{33}
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]

- most image enhancement and compression are performed on luminance and chrominance values separately
  - eye is more sensitive to luminance than to chrominance
  - preserve color before and after processing