Cvision – 3
Color and Noise

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Outline

- Color spaces
- Color processing
- Noise

Acknowledgements: Most of this course is based on the excellent courses offered by Prof. Shree Nayar at Columbia University, USA and by Prof. Srinivasa Narasimhan at CMU, USA. This was also based on Prof. Miguel Coimbra's slides. Please acknowledge the original source when reusing these slides for academic purposes.

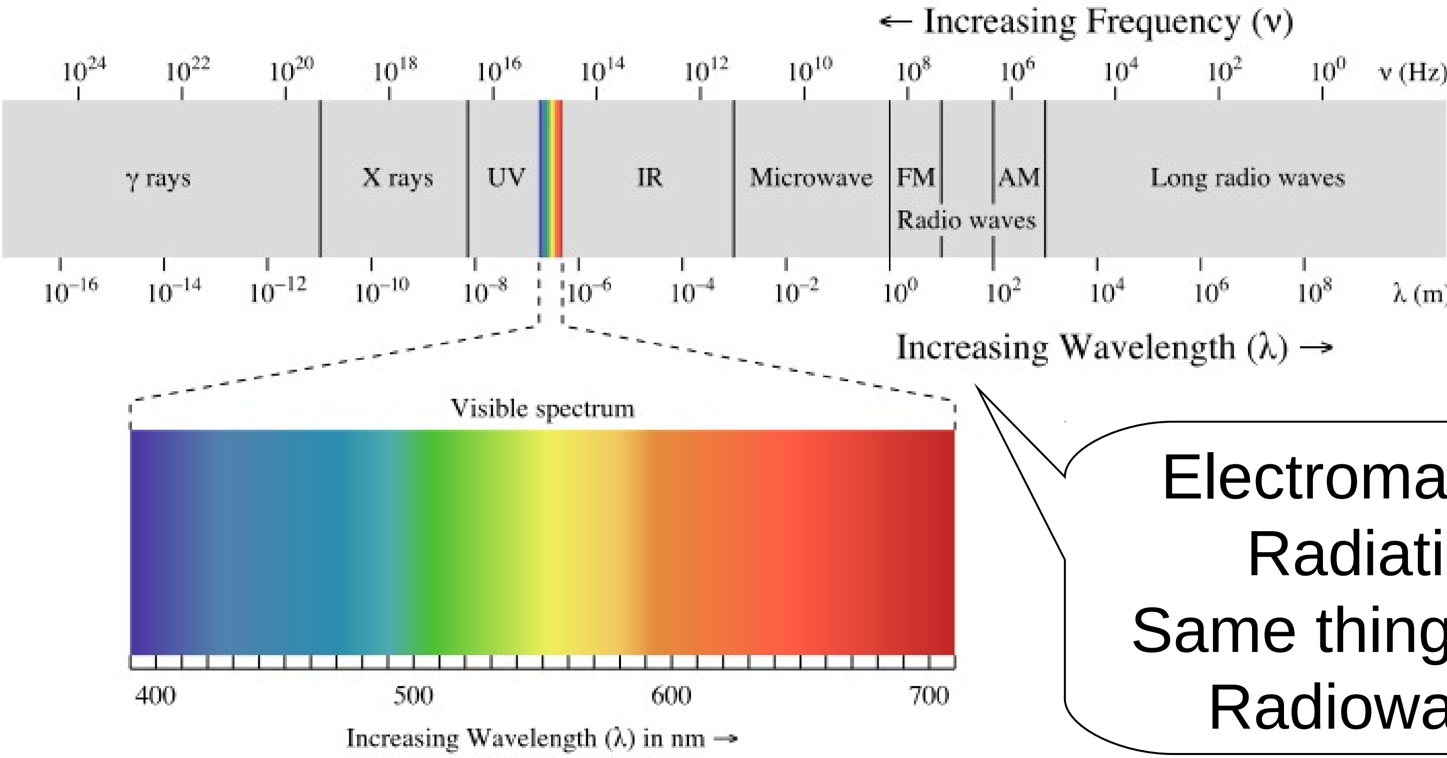
Topic: Color spaces

- Color spaces
- Color processing
- Noise

For a long time I limited myself to one colour – as a form of discipline

Pablo Picasso

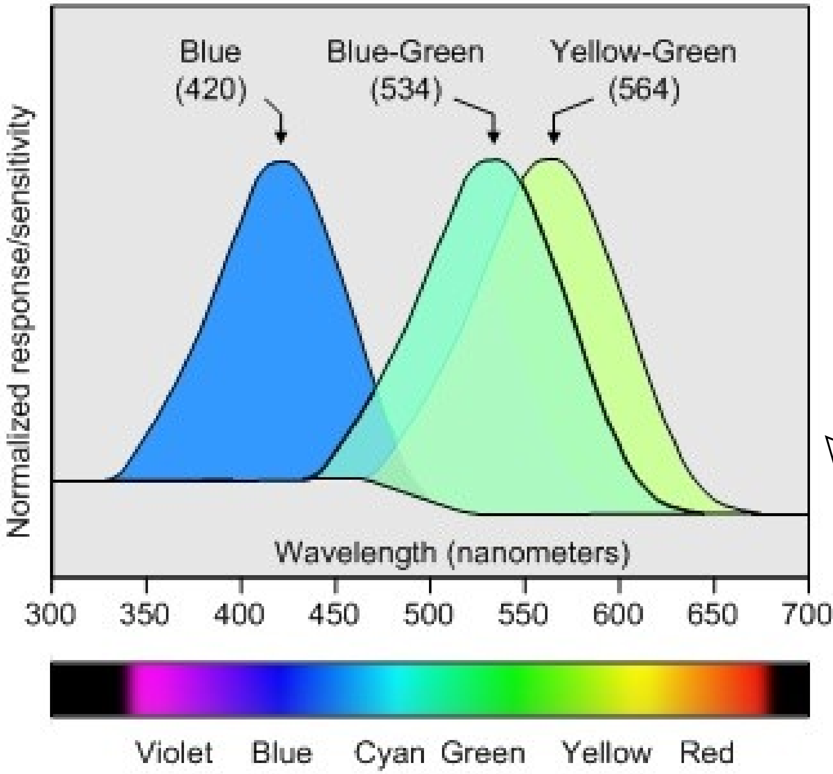
Color: Visible Spectrum



Electromagnetic Radiation.
Same thing as FM Radiowaves!

http://science.howstuffworks.com/light.htm

How do we see colour?



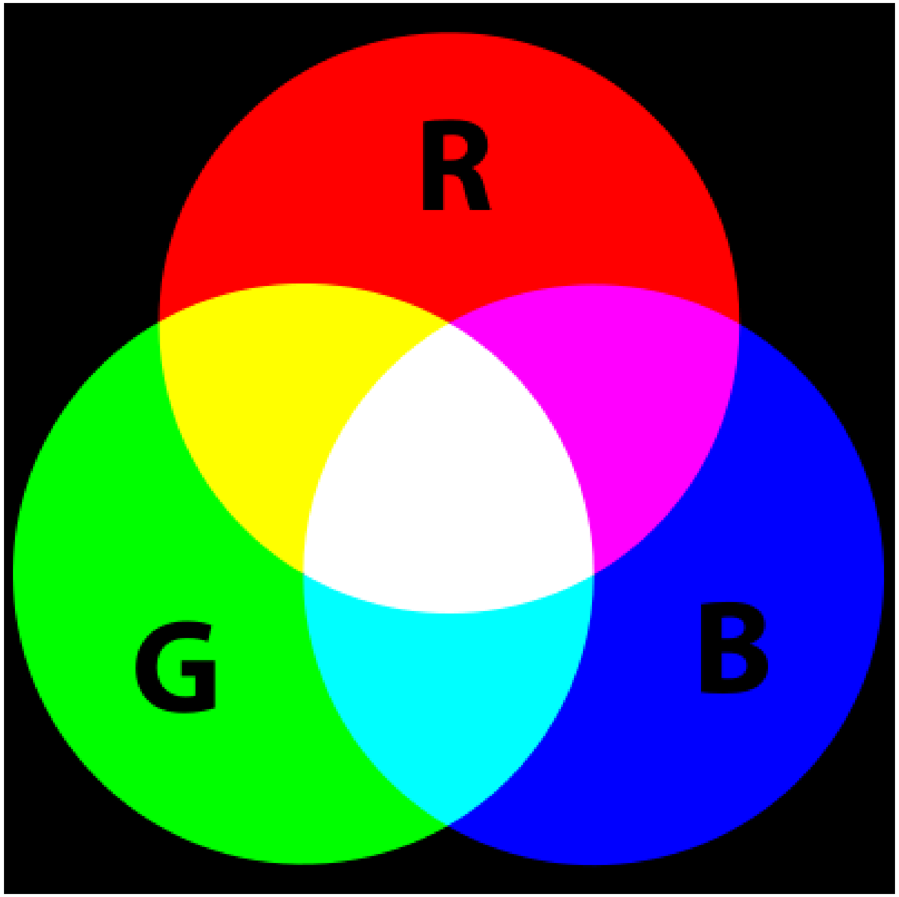
Typical humans are trichromats
(three color cone/pigment types – blue, blue-green, and yellow-green)

Human Colour Sensors: Cones

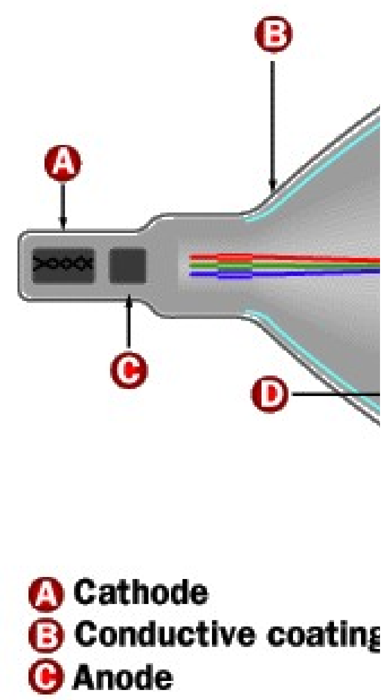
‘Red’ cones
‘Green’ cones
’Blue’ cones

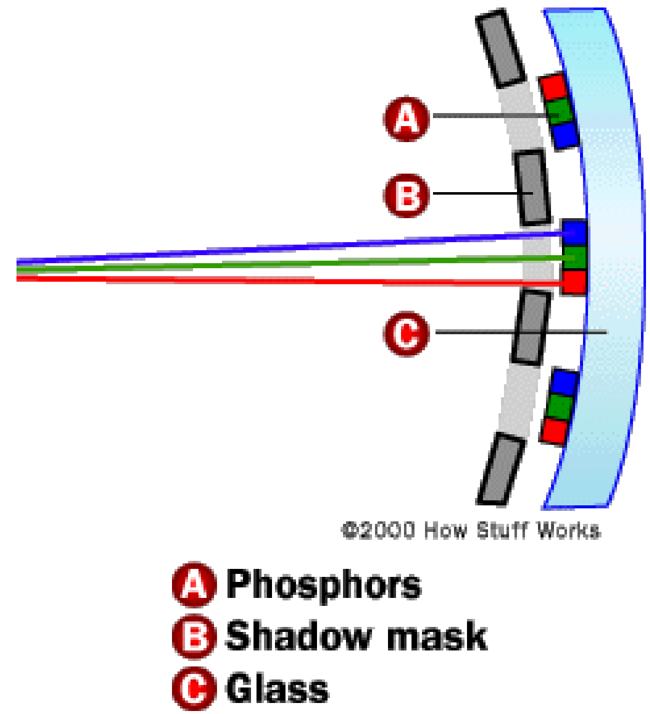
Primary Colours

- Not a fundamental property of light.
- Based on the physiological response of the human eye.
- Form an additive colour system.



Example: Television





Three types of phosphors very close together

The components are added to create a final colour

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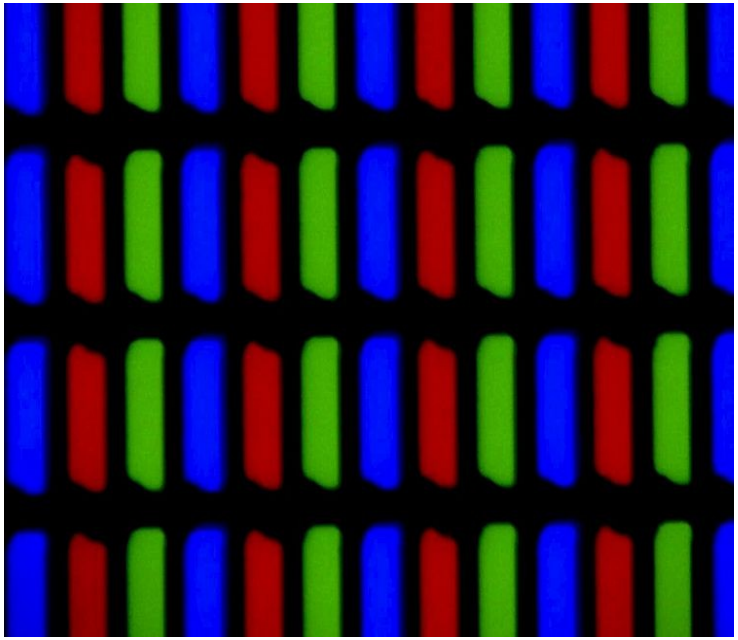
Example: LCD displays



Close-up on the display

Color Space

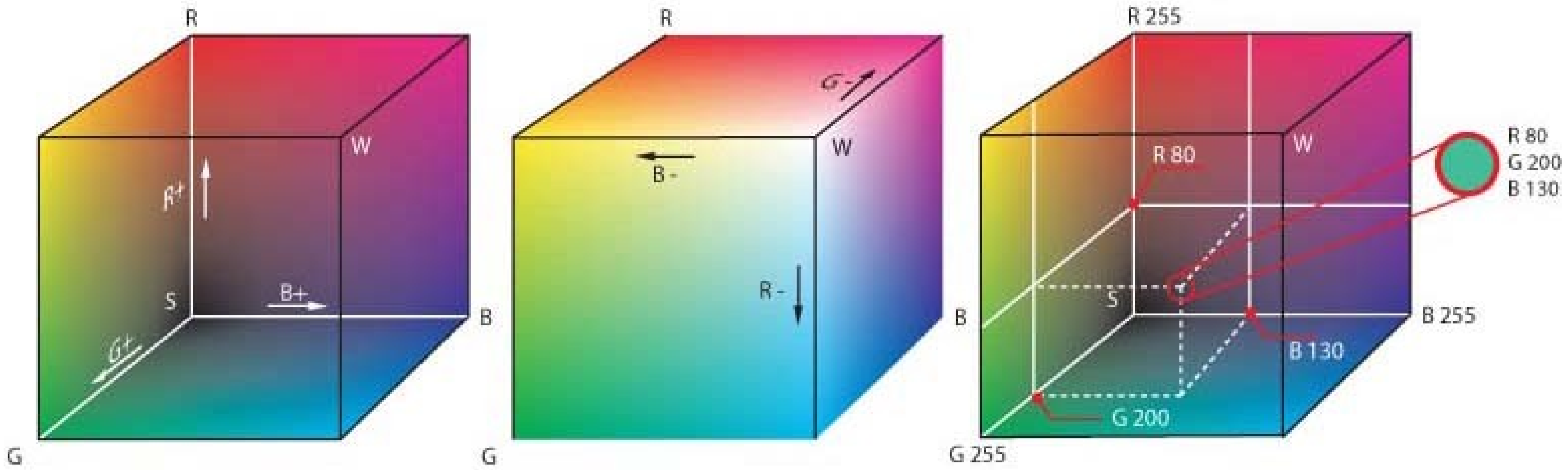
- “The purpose of a color model is to facilitate the specification of colours in some standard, generally accepted way”

  Gonzalez & Woods

- Color space
  - Coordinate system
  - Subspace: One colour -> One point

RGB

- Red Green Blue
- Defines a colour cube.
- Additive components.
- Great for image capture.
- Great for image projection.
- Poor color description.

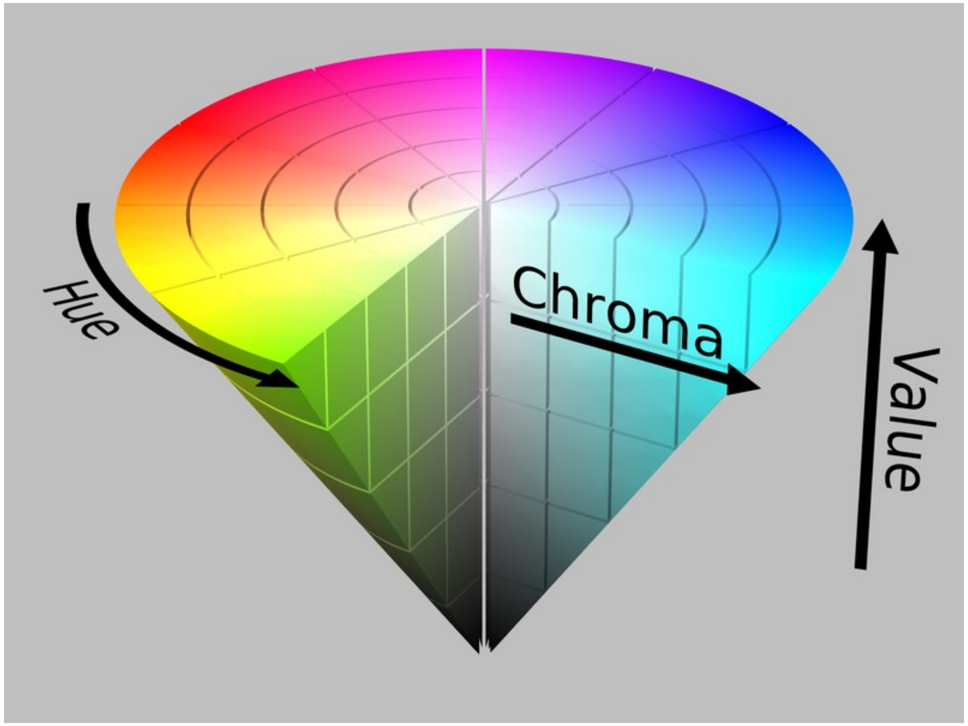


CMYK

- Cyan Magenta Yellow Key.
- Variation of RGB.
- Technological reasons: great for printers.

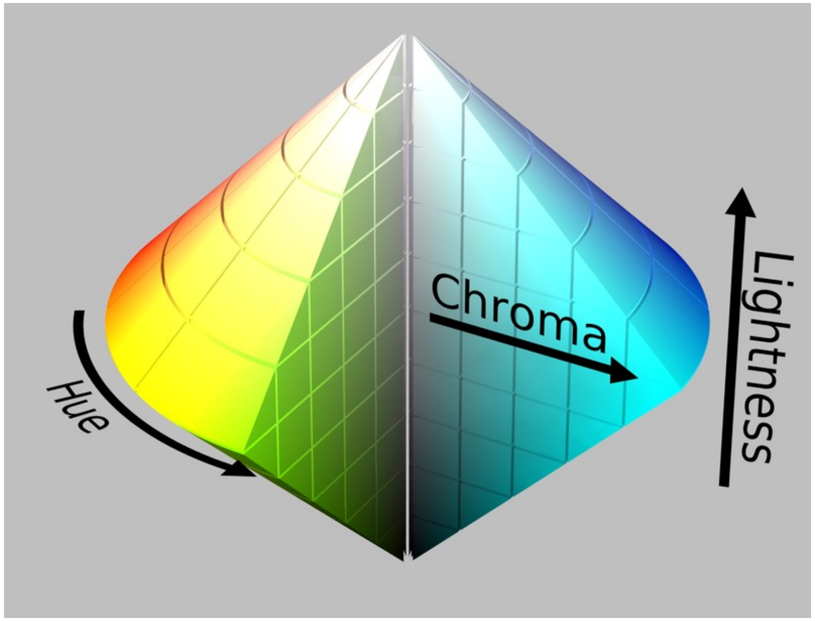
HSV

- Hue Saturation Value
- Defines a color cone.
- Great for color description and manipulation
- Value measures the distance of a Hue from black

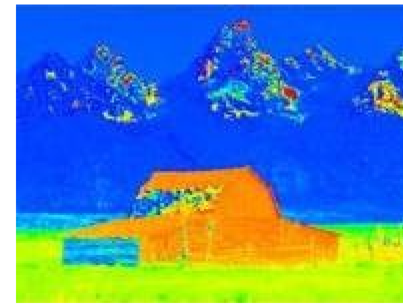


HSI (HSL)

- Hue Saturation Intensity
- Hue and Saturation similar to HSV.
- Intensity/Lightness means something different than Value...



RGB to HSI



Hue:

$$H = \begin{cases} \theta & \Leftarrow B \le G \\ 360 - \theta & \Leftarrow B > G \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

Saturation

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right]$$

Intensity

$$I = \frac{1}{3}(R+G+B)$$

HSI to RGB

- Depends on the 'sector' of H

0 <= H < 120

$$B = I(1 - S)$$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^{\circ} - H)}\right]$$

$$G = 3I - (R + B)$$

120 <= H < 240

$$H = H - 120^{\circ}$$

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^{\circ} - H)}\right]$$

$$B = 3I - (R + B)$$

240 <= H < 360

$$H = H - 240^{\circ}$$

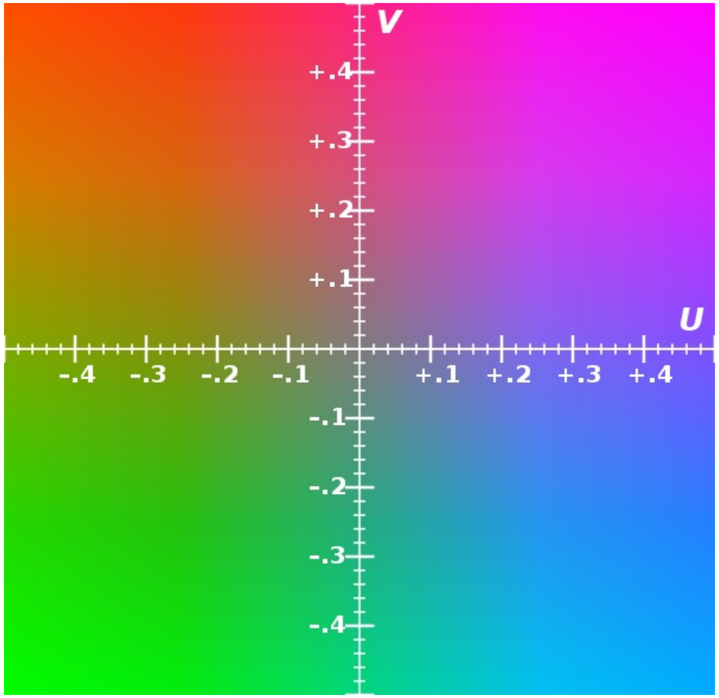
$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^{\circ} - H)}\right]$$

$$R = 3I - (R + B)$$

YUV

- Y stands for the luma component (the brightness) and U and V are the chrominance (color).
- YUV is a color space typically used as part of a color image pipeline.
- Takes the human perception into account, allowing reduced bandwidth for chrominance components.
- YCbCr is the digital version...



UV plane for a fixed Y

RGB to YUV

RGB to YUV Conversion:

$$Y = (0.257 * R) + (0.504 * G) + (0.098 * B) + 16$$

$$Cr = V = (0.439 * R) - (0.368 * G) - (0.071 * B) + 128$$

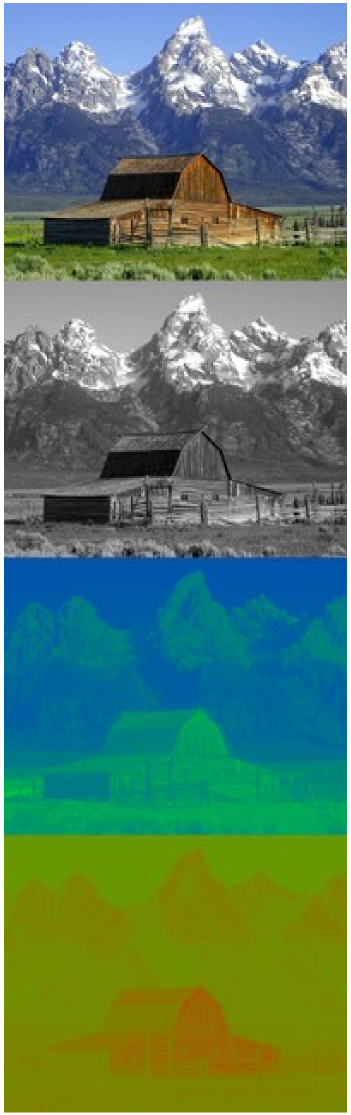
$$Cb = U = -(0.148 * R) - (0.291 * G) + (0.439 * B) + 128$$

YUV to RGB Conversion:

$$B = 1.164(Y - 16) + 2.018(U - 128)$$

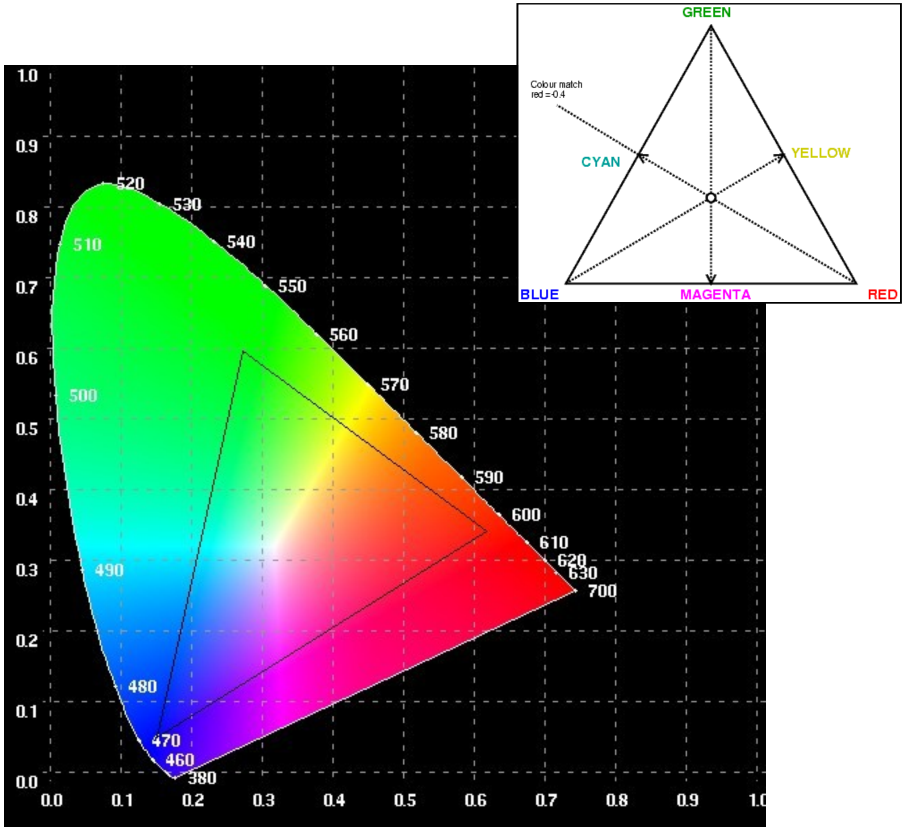
$$G = 1.164(Y - 16) - 0.813(V - 128) - 0.391(U - 128)$$

$$R = 1.164(Y - 16) + 1.596(V - 128)$$



Chromaticity Diagram

- Axis:
  - Hue
  - Saturation
- Outer line represents our visible spectrum.



http://www.cs.rit.edu/~ncs/color/a_chroma.html

Topic: Color processing

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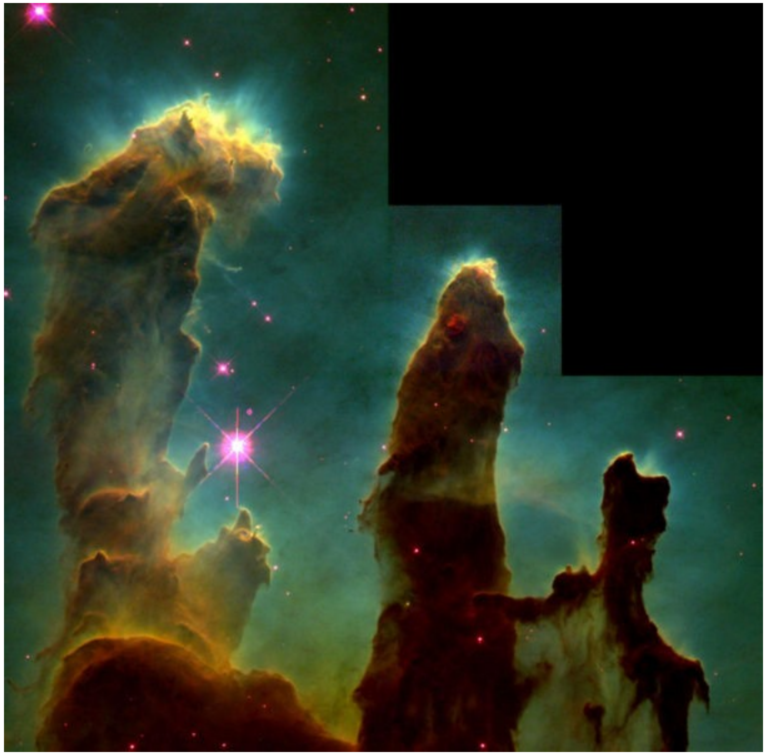
- Noise

Pseudocolor

- Also called *False Color*.
- Opposed to *True Color* images.
- The colors of a pseudocolour image do not attempt to approximate the real colours of the subject.

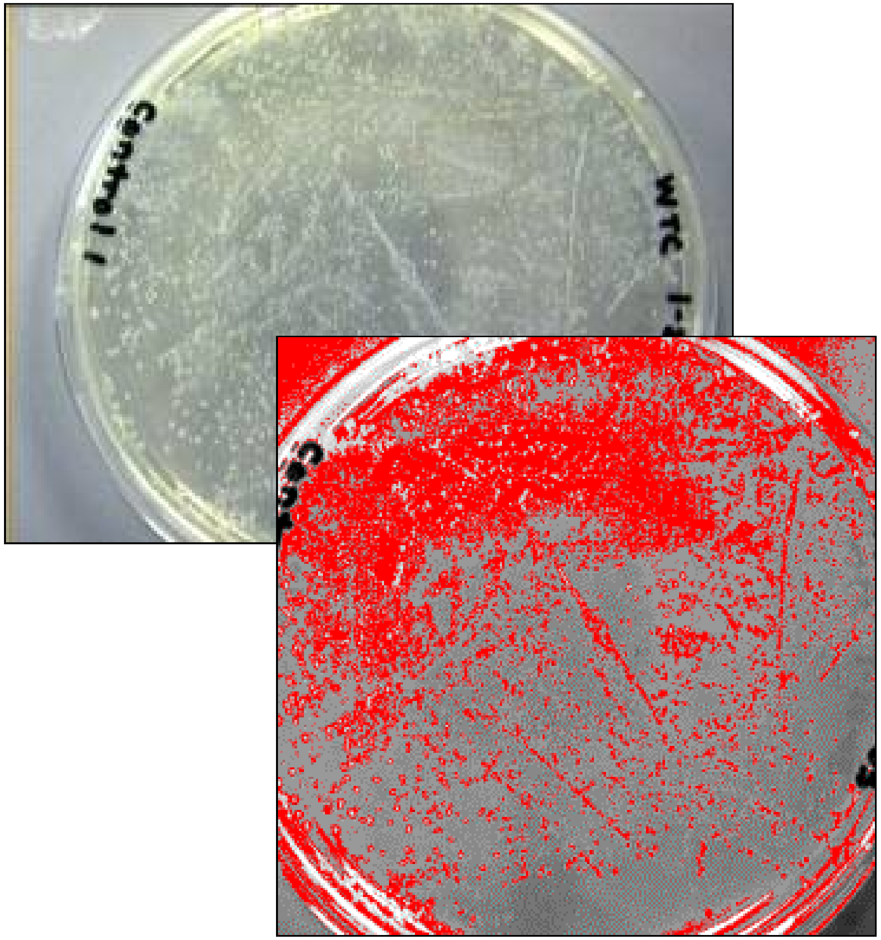


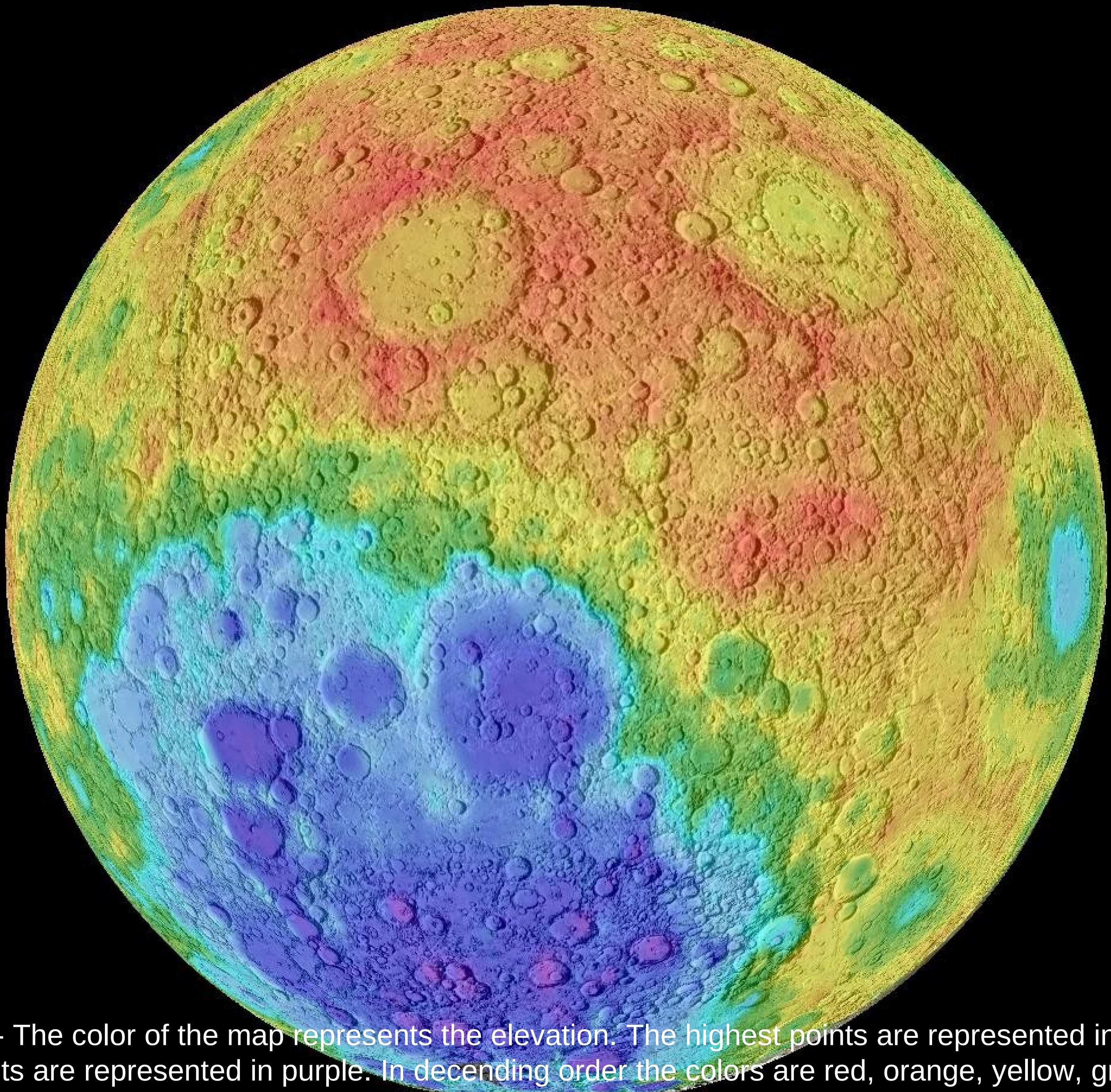
One of Hubble's most famous images: “pillars of creation” where stars are forming in the Eagle Nebula. [NASA/ESA]

www.spacetelescope.org

Intensity Slicing

- Quantize pixel intensity to a specific number of values (*slices*).
- Map one colour to each *slice*.
- Loss of information.
- Enhanced human visibility.



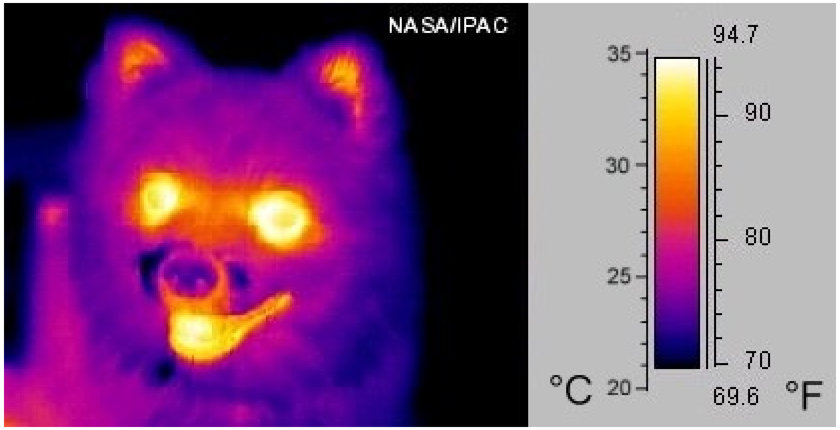


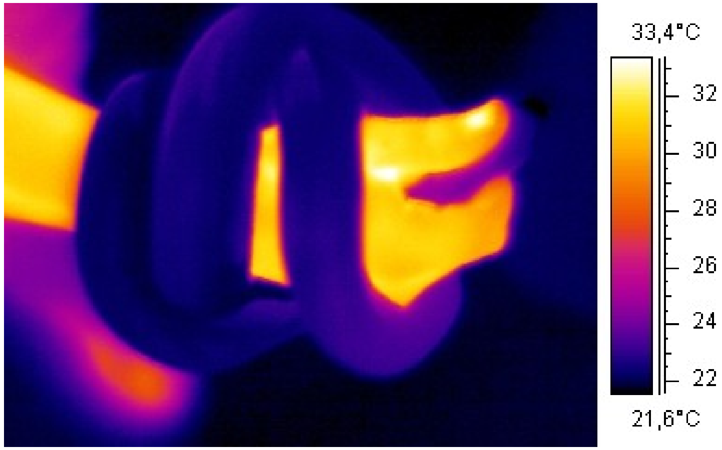
The Moon - The color of the map represents the elevation. The highest points are represented in red. The lowest points are represented in purple. In decending order the colors are red, orange, yellow, green, cyan, blue and purple.

Intensity to Color Transformation

- Each colour component is calculated using a transformation function.
- Viewed as an Intensity to Colour map.
- Does not need to use RGB space!
- Examples: display thermal or depth images

$$f(x,y) \Rightarrow \begin{cases} f_R(x,y) = T_R\left[f(x,y)\right] \\ f_G(x,y) = T_G\left[f(x,y)\right] \\ f_B(x,y) = T_B\left[f(x,y)\right] \end{cases}$$

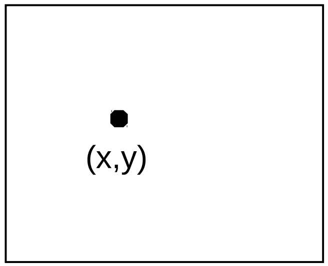




Color Image Processing

- Grey-scale image
  - One value per position.

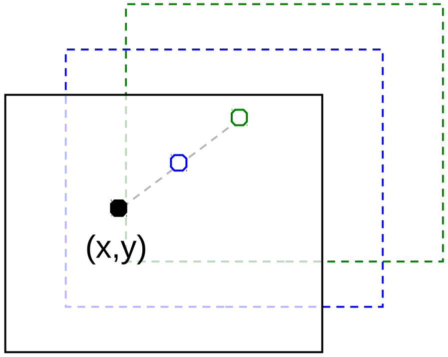
$$f(x,y) = I$$



Grey-scale image

- Color image
  - One vector per position.

$$f(x,y) = [R\ G\ B]^T$$



RGB Colour image

Color Transformations

- Consider single-point operations:

  T_i: Transformation function for color component *i*

  s_i, r_i: Components of *g* and *f*

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

$$s_i = T_i(r_1, r_2, \ldots, r_n)$$

$$i = 1, 2, \ldots, n$$

- Simple example:
  - Increase Brightness of an RGB image

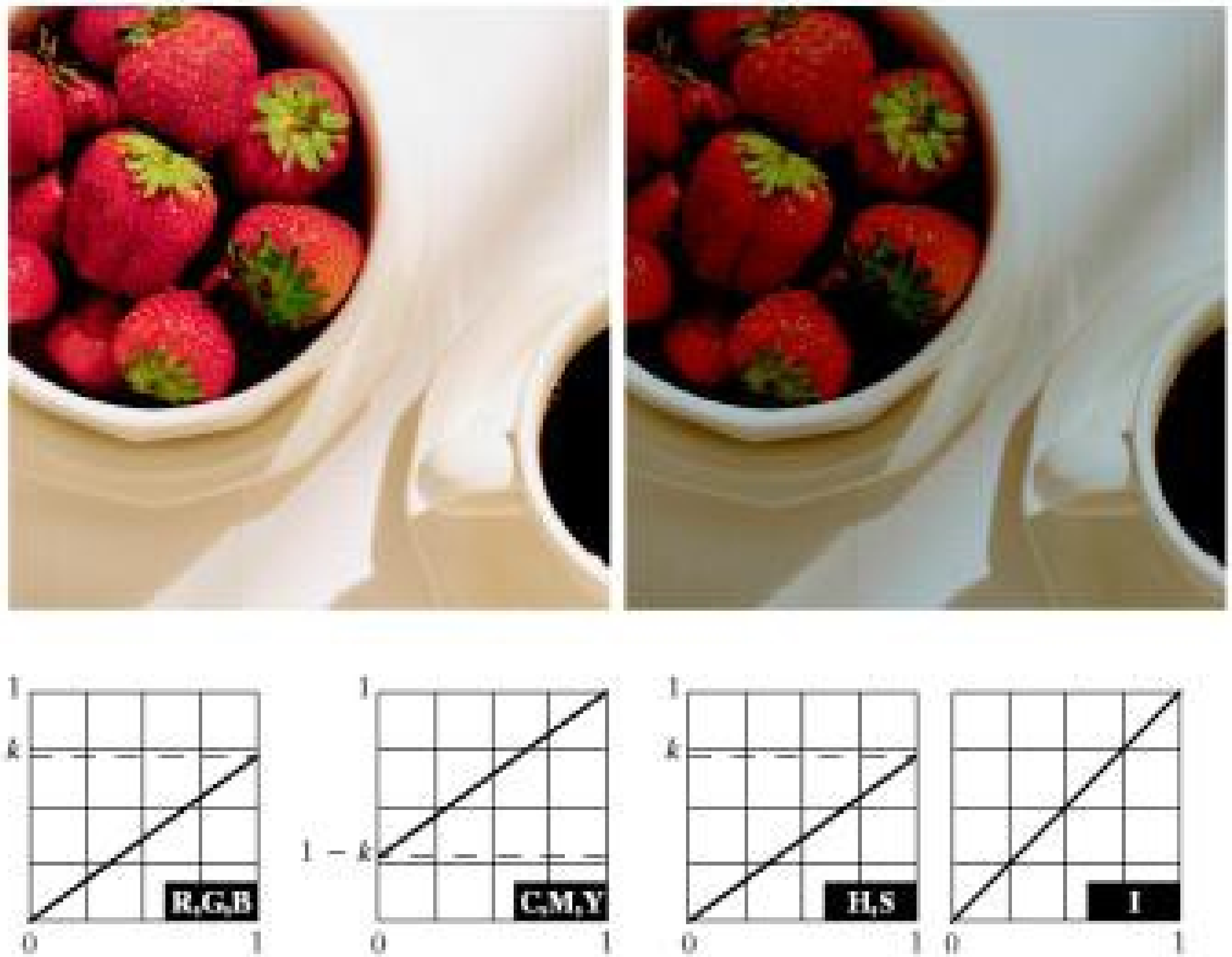
$$s_R = r_R + 20$$

$$s_G = r_G + 20$$

$$s_B = r_B + 20$$

What about an image negative?

Example

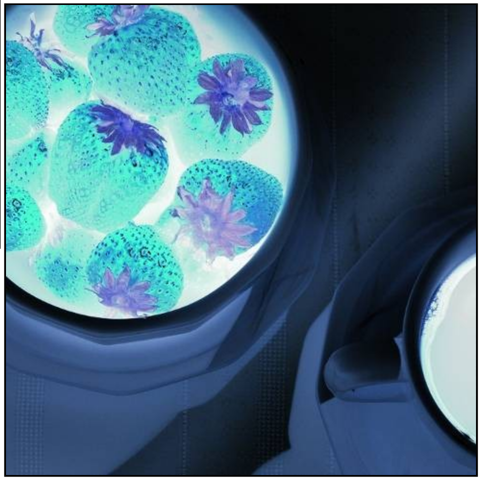


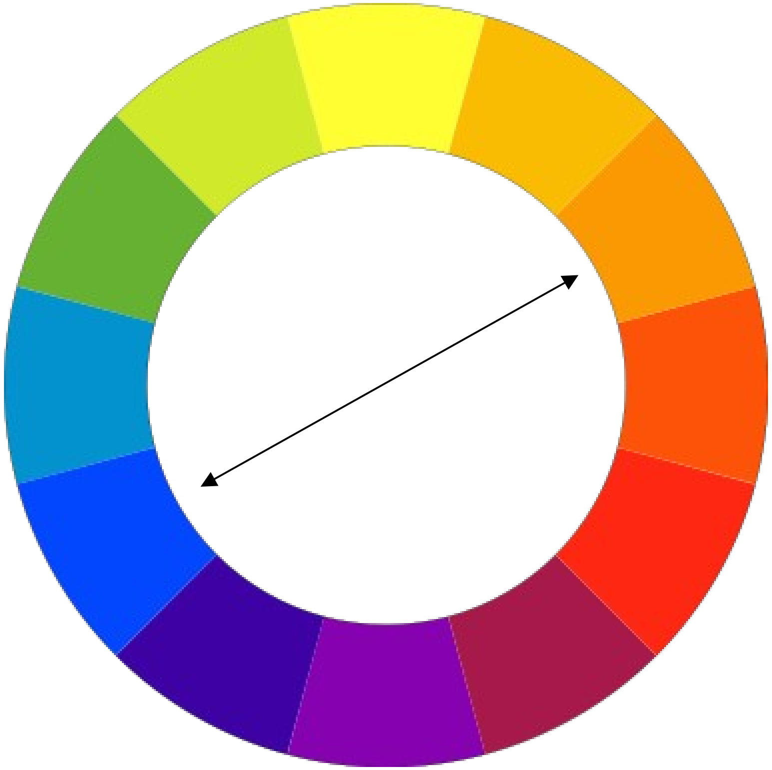
a b
c d e

FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

Color Complements

- Color equivalent of an image negative.





Complementary Colors

Color Slicing

- Define a hyper-volume of interest inside my color space.
- Keep colours if inside the hyper-volume.
- Change the others to a neutral colour.

Tone and color corrections

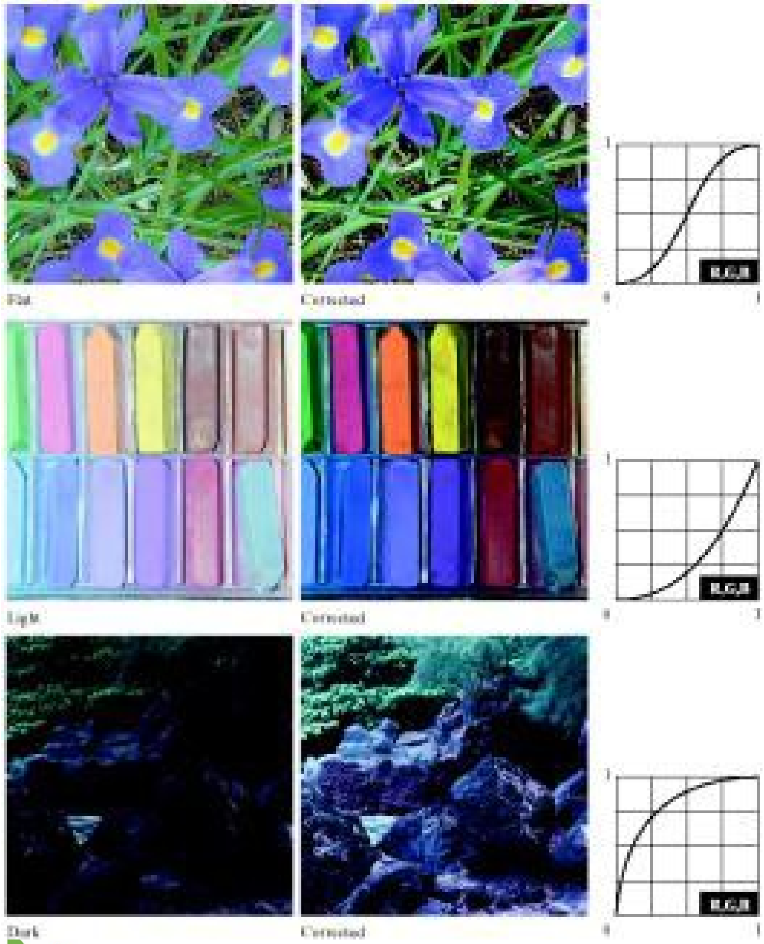
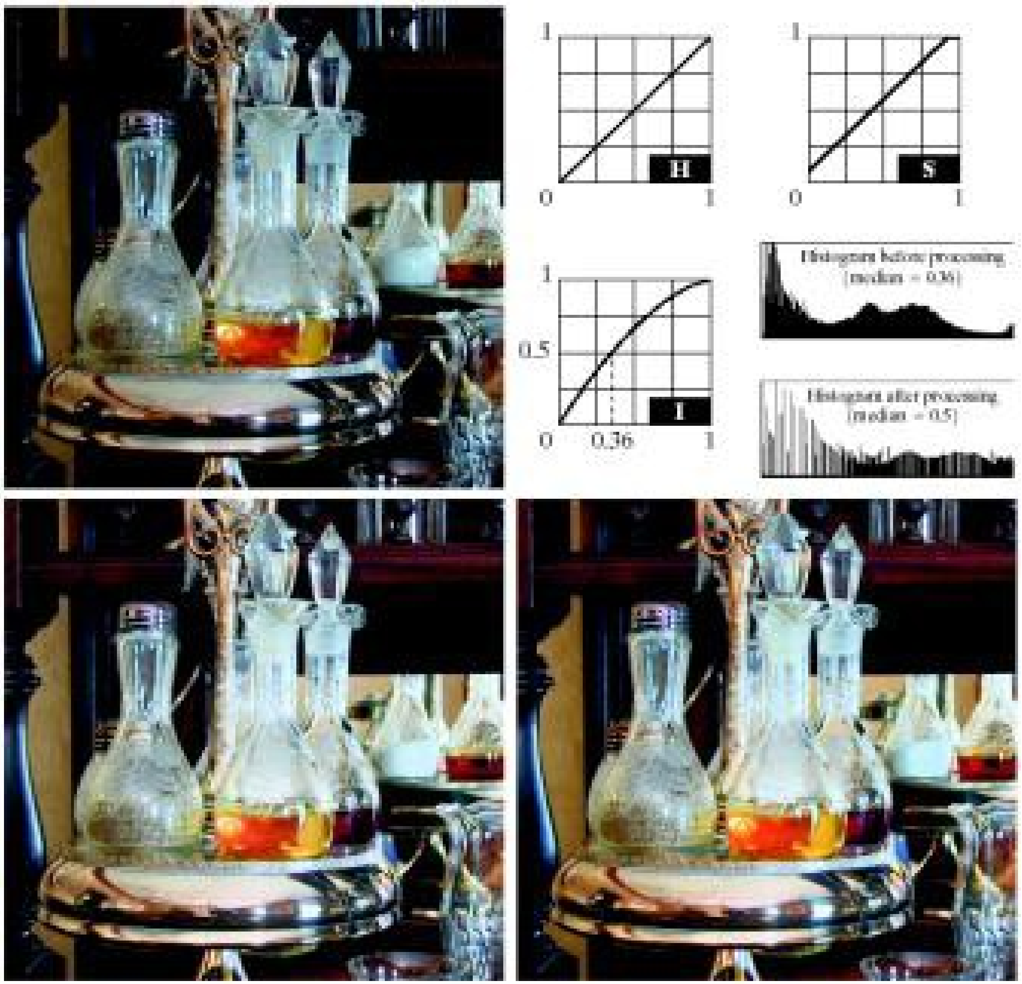


FIGURE 6.36 Color balancing corrections for CMYK color images.

Histogram equalization



a b
c d

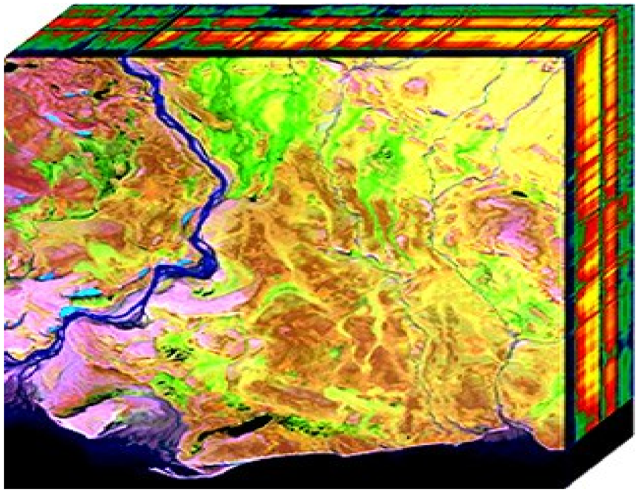
FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

Other operations

- Image smoothing
- Image sharpening
- Segmentation

Multispectral image

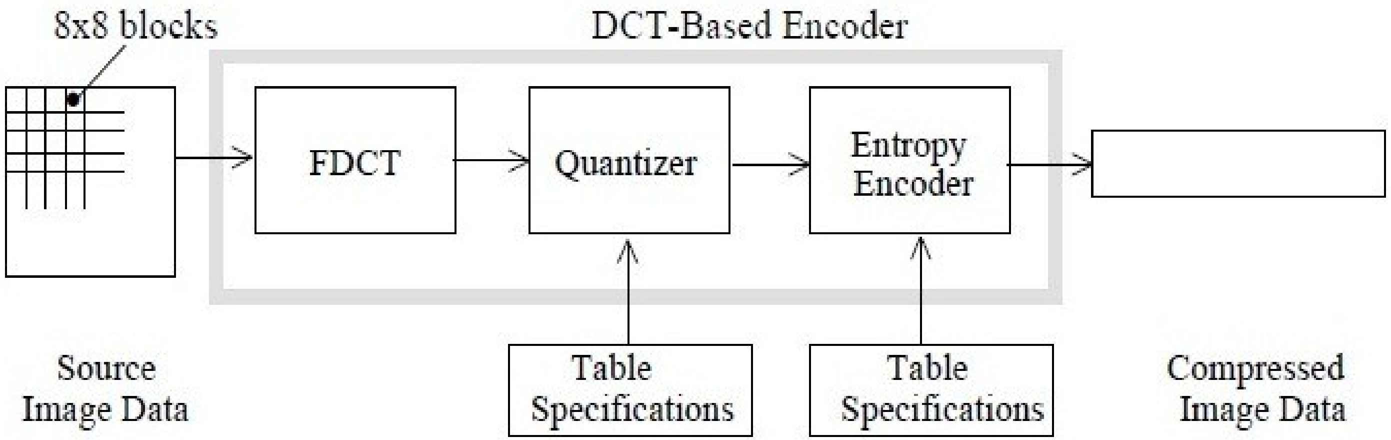
- Hyperspectral sensors collect information as a set of 'images'.
- Each image represents a range of the electromagnetic spectrum.
- Hyperspectral remote sensing is used in a wide array of applications: agriculture, Mineralogy, Surveillance, physics, etc.



NASA's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
or
NASA's Hyperion satellites

Image compression

- Lossless vs lossy
- Progressive vs sequential
- Video vs still image
- Several standards: MPEG, H26X, JPEG2000, JPEG-LS, PNG, GIF, JPEG...



Example: JPEG image coding standard

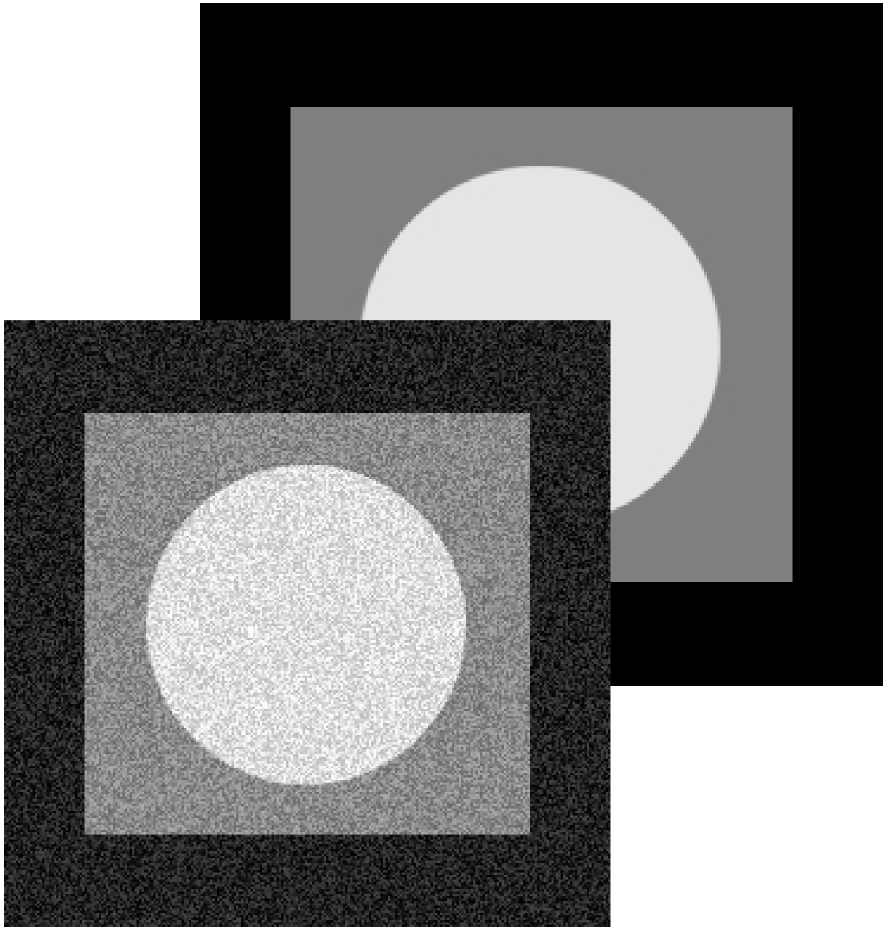
Example JPEG compression

Topic: Noise

- Color spaces
- Color processing
- Noise

Bring the Noise

- Noise is a distortion of the measured signal.
- Every physical system has noise.
- Images:
  - The importance of noise is affected by our human visual perception
  - Ex: Digital TV ‘block effect’ due to noise.



Where does it come from?

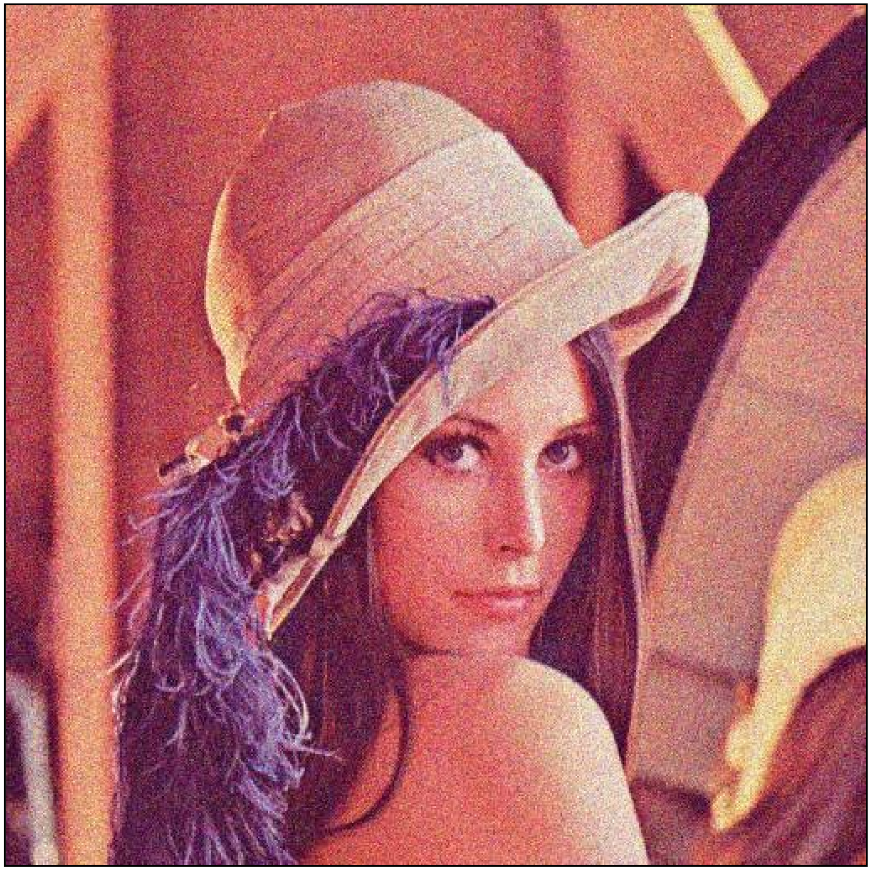
- ‘Universal’ noise sources:
  - Thermal, sampling, quantization, measurement.
- Specific for digital images:
  - The number of photons hitting each images sensor is governed by quantum physics: *Photon Noise.*
  - Noise generated by electronic components of image sensors:
    - *On-Chip Noise*, *KTC Noise*, *Amplifier Noise*, etc.

Noise Models

- Noise models
  - We need to mathematically handle noise.
  - Spatial and frequency properties.
  - Probability theory helps!
- Advantages:
  - Easier to filter noise.
  - Easier to measure its importance.
  - More robust systems!

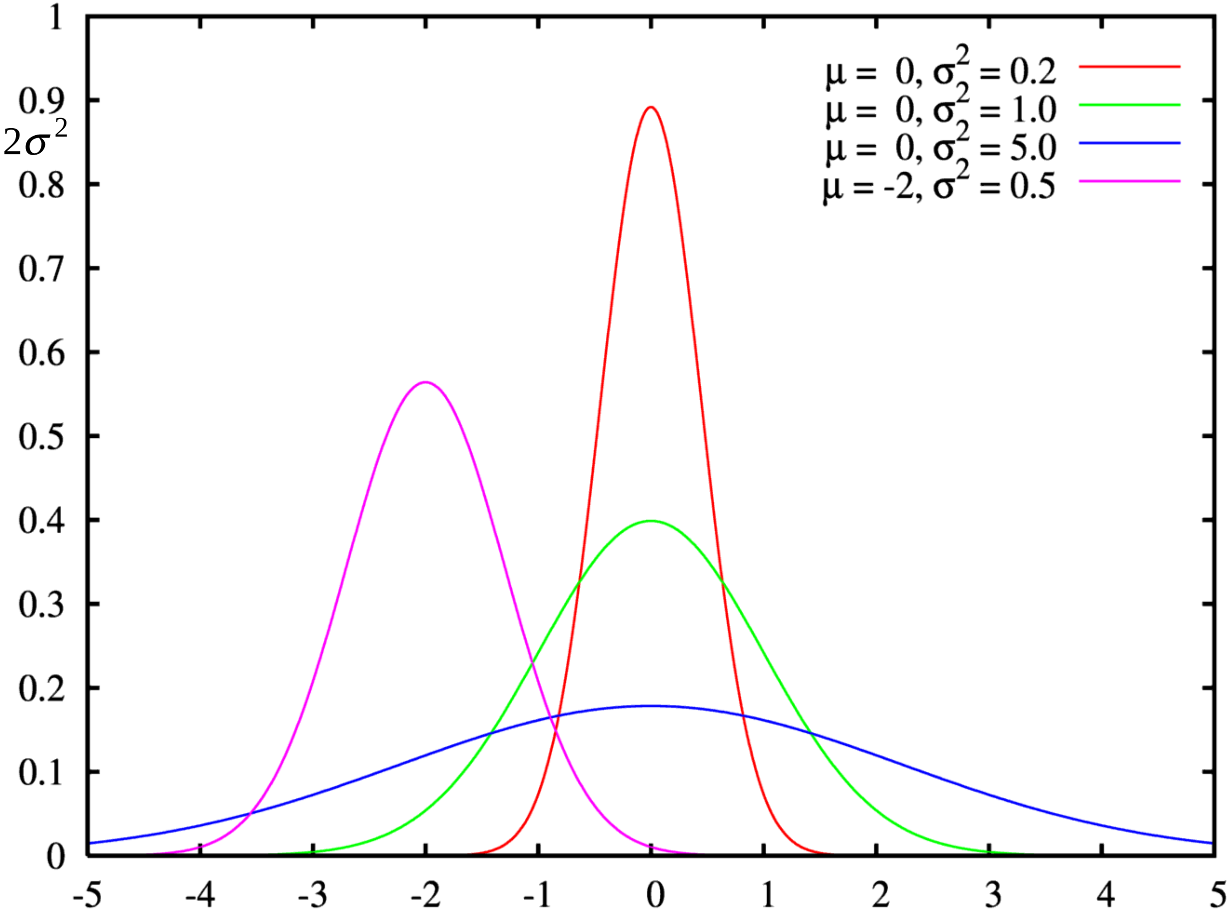
Model: Gaussian Noise

- Gaussian PDF (Probability Density Function).
- Great approximation of reality.
  - Models noise as a sum of various small noise sources, which is indeed what happens in reality.



Model: Gaussian Noise

$$p(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(z-\bar{z})^2/2\sigma^2}$$

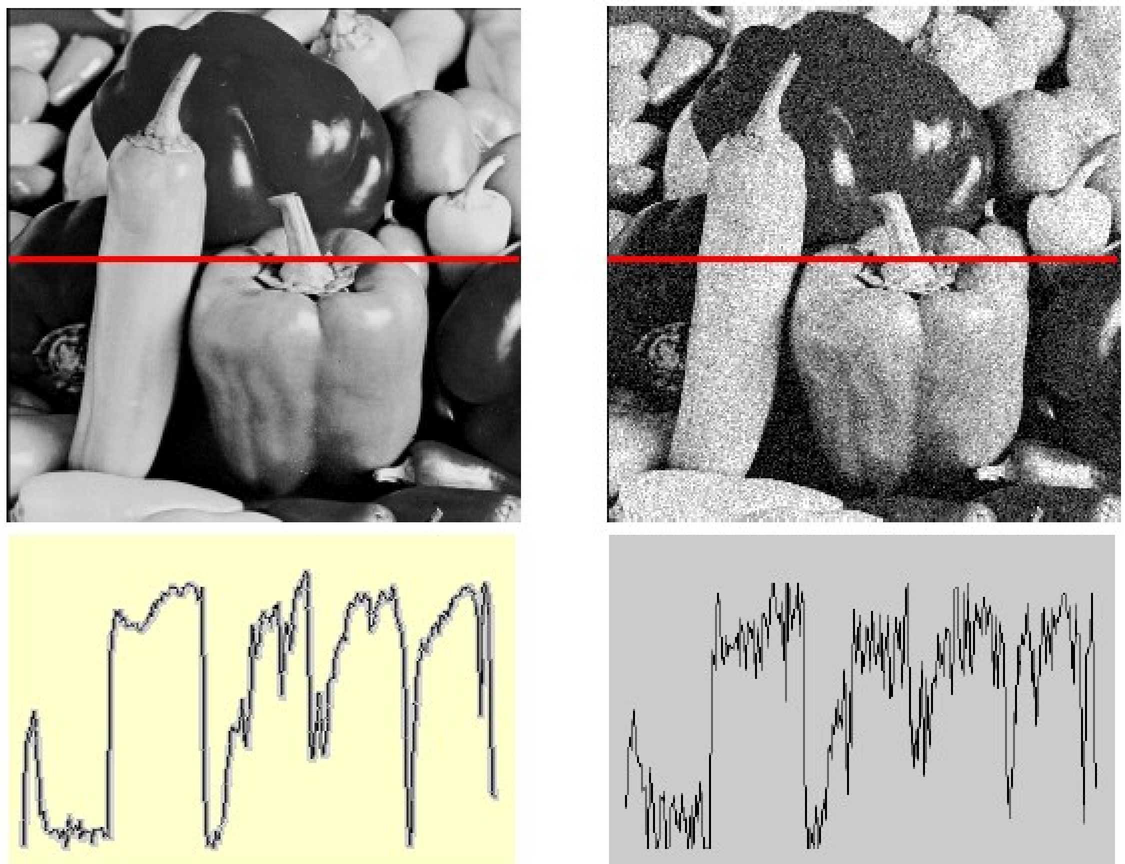


Model: Salt and Pepper Noise

- Considers that a value can randomly assume the MAX or MIN value for that sensor.
  - Happens in reality due to the malfunction of isolated image sensors.

Noise: Profile analysis

Image Noise



$$f(x,y) = \overbrace{\hat{f}(x,y)}^{\text{Ideal Image}} + \overbrace{\eta(x,y)}^{\text{Noise process}}$$

Gaussian i.i.d. (“white”) noise

$\eta(x,y) \sim \mathcal{N}(\mu,\sigma)$

How do we handle it?

- Not always trivial!
  - Frequency filters.
  - Estimate the degradation function.
  - Inverse filtering.
  - ...

One of the greatest challenges of signal processing!

Resources

- Gonzalez & Woods – Chapters 5 and 6
- http://www.howstuffworks.com/
- http://www.spacetelescope.org

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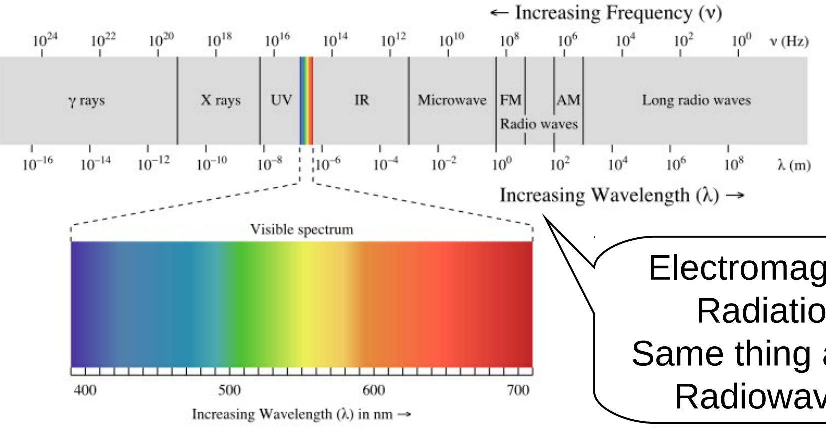

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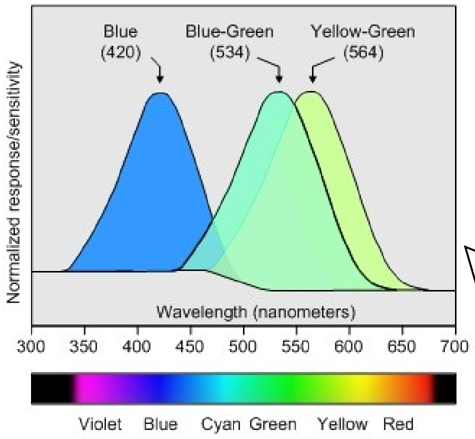

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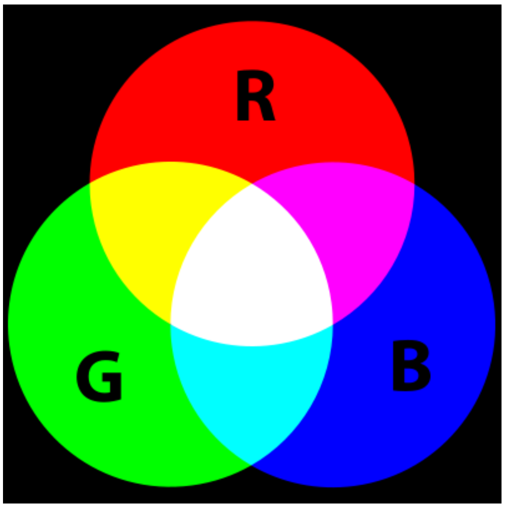

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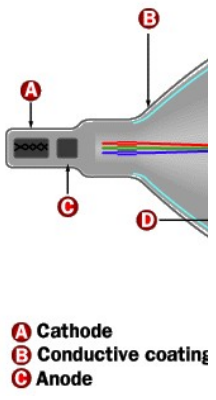

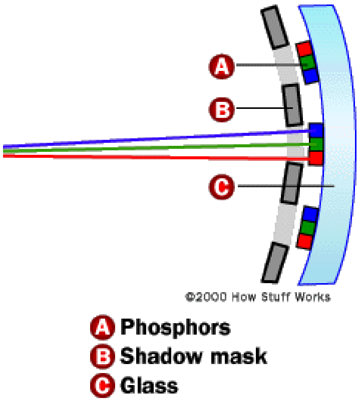

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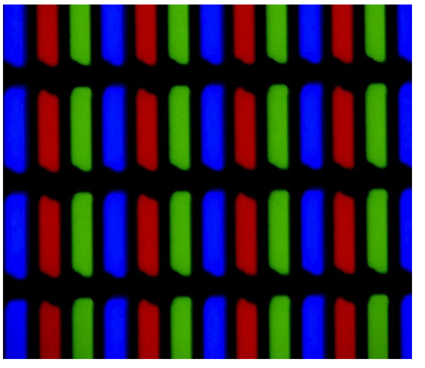

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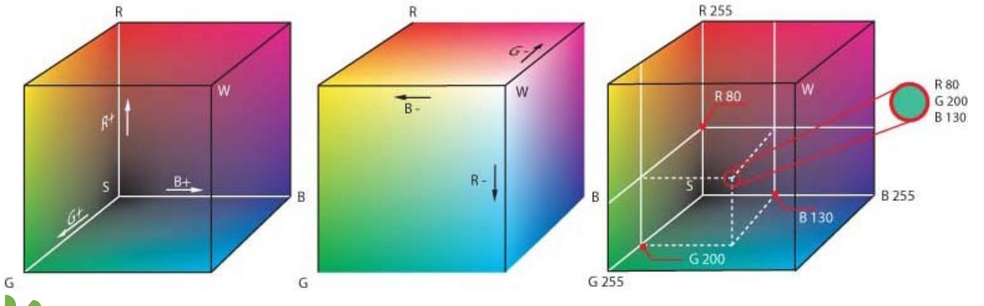
- Additive components.
- Great for image capture.
- Great for image projection.
- Poor color description.



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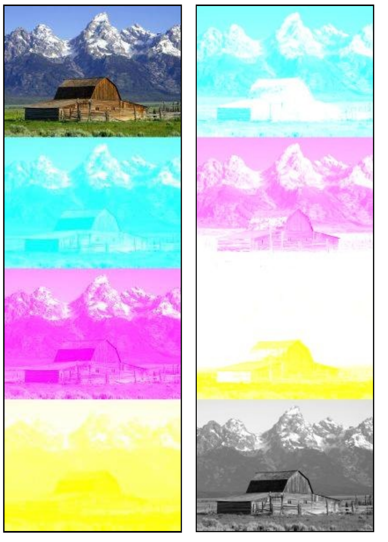

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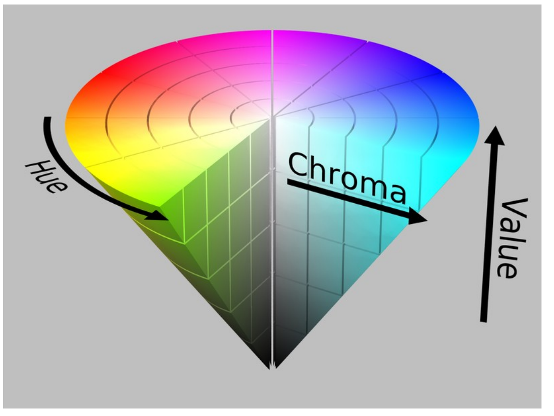
HSV

- Hue Saturation Value
- Defines a color cone.
- Great for color description and manipulation
- Value measures the distance of a Hue from black



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HSI (HSL)

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- Hue and Saturation similar to HSV.
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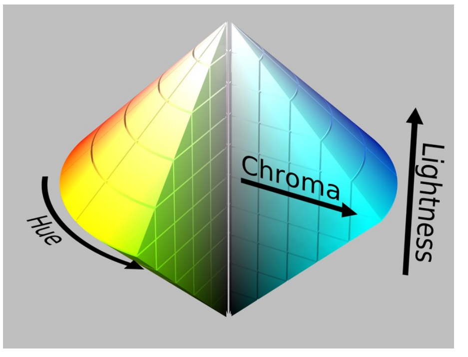
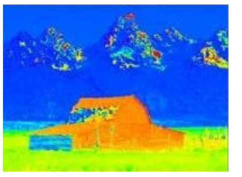


RGB to HSI

Hue:

$$H = \begin{cases} \theta & \Leftarrow B \le G \\ 360 - \theta & \Leftarrow B > G \end{cases}$$



$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2 + (R-B)(G-B)\right]^{1/2}} \right\}$$

Saturation

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right]$$

Intensity

$$I = \frac{1}{3}(R+G+B)$$

HSI to RGB

- Depends on the 'sector' of H

0 <= H < 120

$$B = I(1-S)$$

$$R = I\left[1+\frac{S\cos H}{\cos(60^{o}-H)}\right]$$

$$G = 3I-(R+B)$$

120 <= H < 240

$$H = H-120^{o}$$

$$R = I(1-S)$$

$$G = I\left[1+\frac{S\cos H}{\cos(60^{o}-H)}\right]$$

$$B = 3I-(R+B)$$

240 <= H < 360

$$H = H-240^{o}$$

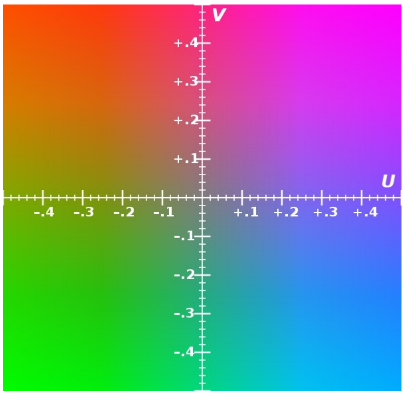
$$G = I(1-S)$$

$$B = I\left[1+\frac{S\cos H}{\cos(60^{o}-H)}\right]$$

$$R = 3I-(R+B)$$

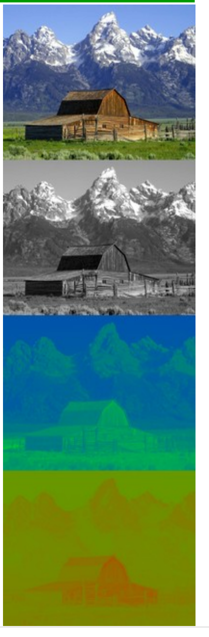
YUV

- Y stands for the luma component (the brightness) and U and V are the chrominance (color).
- YUV is a color space typically used as part of a color image pipeline.
- Takes the human perception into account, allowing reduced bandwidth for chrominance components.
- YCbCr is the digital version...



UV plane for a fixed Y

RGB to YUV



RGB to YUV Conversion:

$$Y = (0.257 * R) + (0.504 * G) + (0.098 * B) + 16$$

$$Cr = V = (0.439 * R) - (0.368 * G) - (0.071 * B) + 128$$

$$Cb = U = -(0.148 * R) - (0.291 * G) + (0.439 * B) + 128$$

YUV to RGB Conversion:

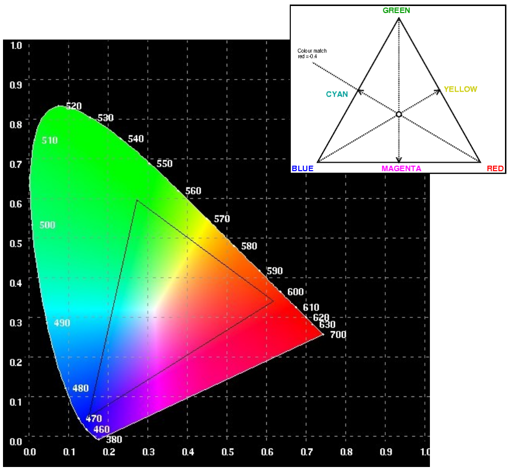
$$B = 1.164(Y - 16) + 2.018(U - 128)$$

$$G = 1.164(Y - 16) - 0.813(V - 128) - 0.391(U - 128)$$

$$R = 1.164(Y - 16) + 1.596(V - 128)$$

Chromaticity Diagram

- Axis:
  - Hue
  - Saturation
- Outer line represents our visible spectrum.



http://www.cs.rit.edu/~ncs/color/a_chroma.html

Topic: Color processing

- Color spaces
- Color processing
- Noise

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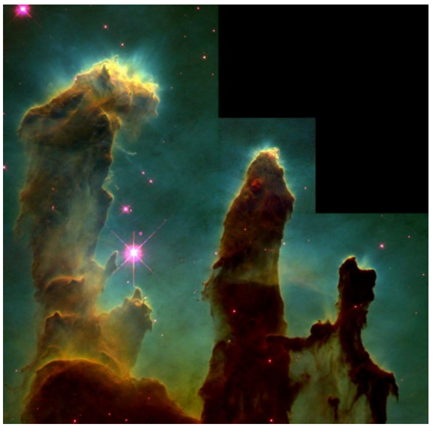
Pseudocolor

- Also called *False Color*.
- Opposed to *True Color* images.
- The colors of a pseudocolour image do not attempt to approximate the real colours of the subject.

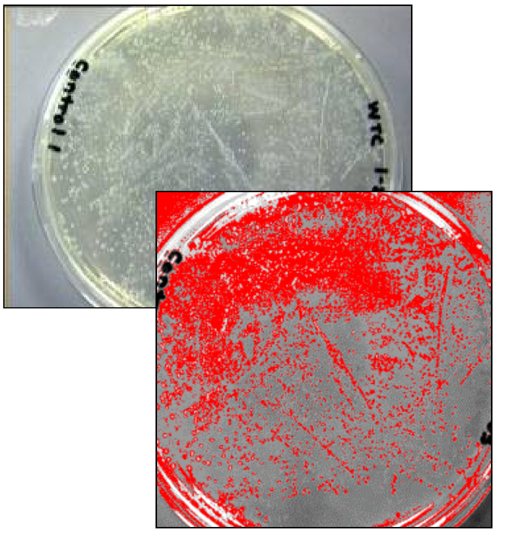


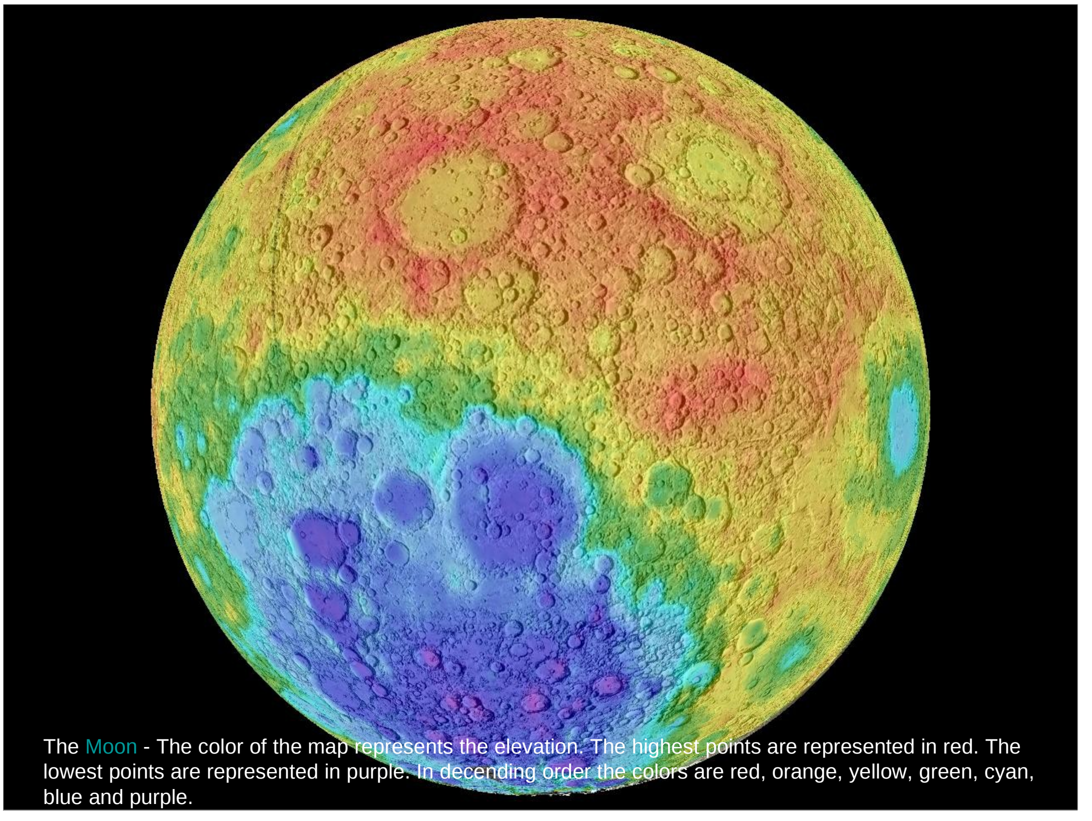
One of Hubble's most famous images: “pillars of creation” where stars are forming in the Eagle Nebula. [NASA/ESA]

www.spacetelescope.org

Intensity Slicing

- Quantize pixel intensity to a specific number of values (*slices*).
- Map one colour to each *slice*.
- Loss of information.
- Enhanced human visibility.



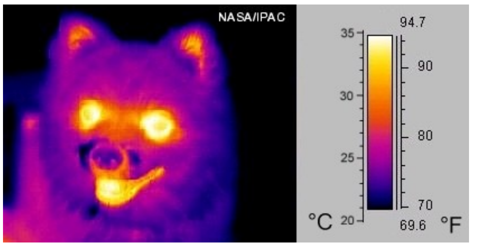


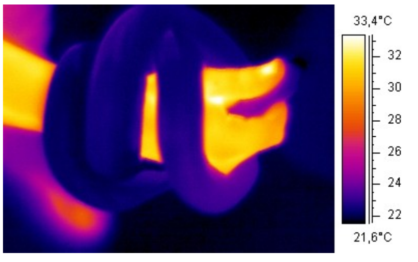
The Moon - The color of the map represents the elevation. The highest points are represented in red. The lowest points are represented in purple. In decending order the colors are red, orange, yellow, green, cyan, blue and purple.

Intensity to Color Transformation

- Each colour component is calculated using a transformation function.
- Viewed as an Intensity to Colour map.
- Does not need to use RGB space!
- Examples: display thermal or depth images

$$f(x,y) \Rightarrow \begin{cases} f_R(x,y) = T_R\left[f(x,y)\right] \\ f_G(x,y) = T_G\left[f(x,y)\right] \\ f_B(x,y) = T_B\left[f(x,y)\right] \end{cases}$$





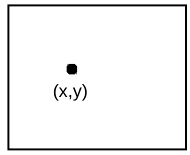
Color Image Processing

- Grey-scale image
  - One value per position.

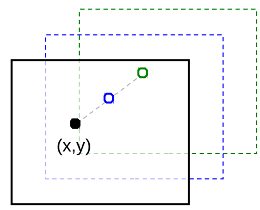
    f(x,y) = I

- Color image
  - One vector per position.

    $f(x,y) = [R\ G\ B]^T$



Grey-scale image



RGB Colour image

Color Transformations

- Consider single-point operations:
  - T_i: Transformation function for color component *i*
  - s_i,r_i: Components of *g* and *f*

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

$$s_i = T_i(r_1, r_2, \ldots, r_n)$$

$$i = 1,2,\ldots,n$$

- Simple example:
  - Increase Brightness of an RGB image

$$s_R = r_R + 20$$

$$s_G = r_G + 20$$

$$s_B = r_B + 20$$

What about an image negative?

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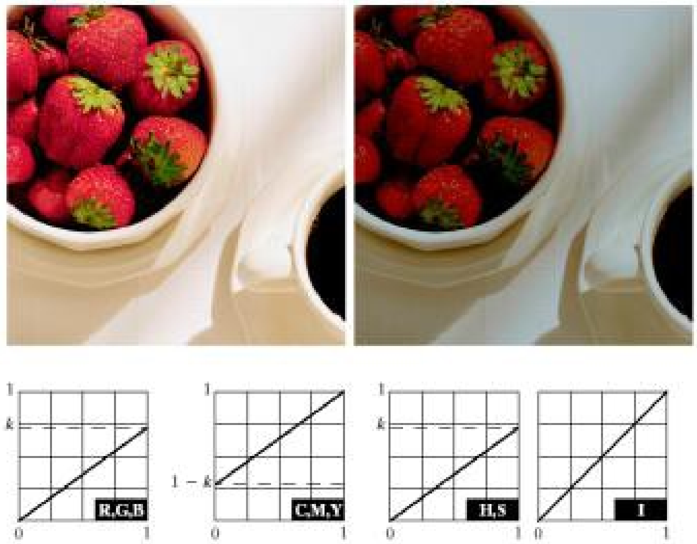
Ri are the color componets of f(x,y)

Si are the color components of g(x,y)

The color transformations of imag f(x,y) into new image g(x,y) are the

Si=Ti(r1,r2,…,rn)

Example

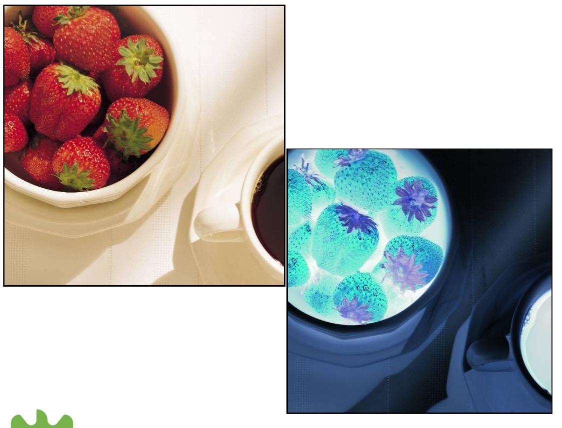


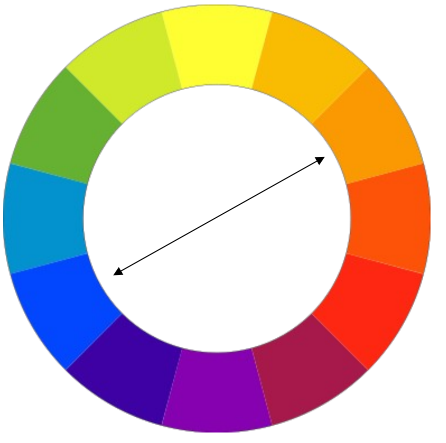
a b
c d e

FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

Color Complements

- Color equivalent of an image negative.





Complementary Colors

Color Slicing

- Define a hyper-volume of interest inside my color space.
- Keep colours if inside the hyper-volume.
- Change the others to a neutral colour.

Tone and color corrections

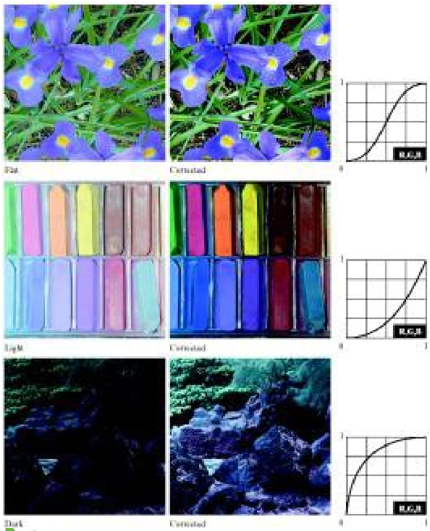
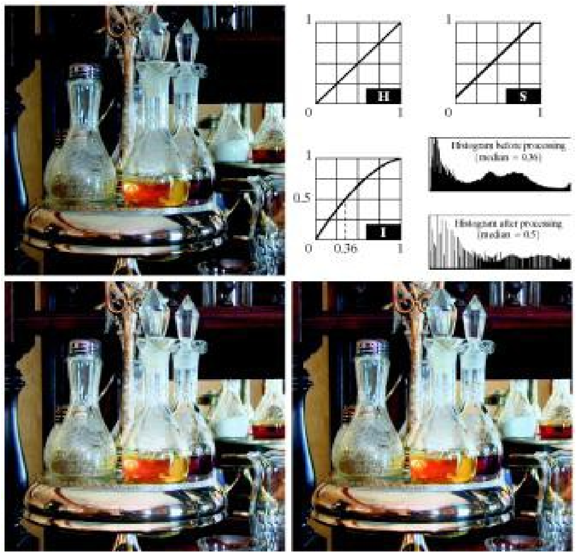


FIGURE 6.36 Color balancing corrections for CMYK color images.

Histogram equalization



a b
c d

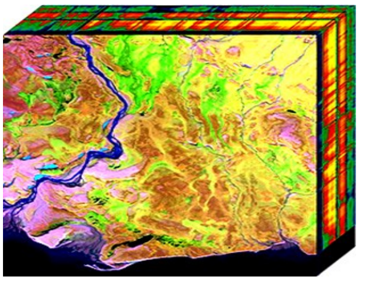
FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

Other operations

- Image smoothing
- Image sharpening
- Segmentation

Multispectral image

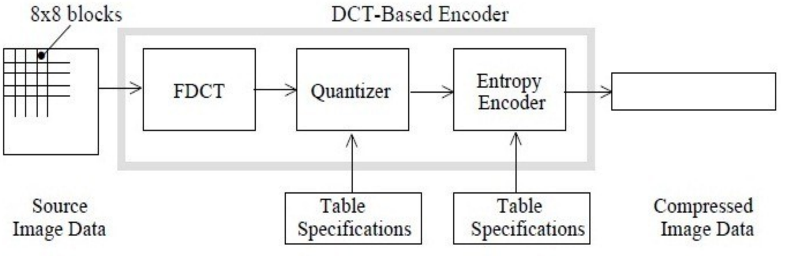
- Hyperspectral sensors collect information as a set of 'images'.
- Each image represents a range of the electromagnetic spectrum.
- Hyperspectral remote sensing is used in a wide array of applications: agriculture, Mineralogy, Surveillance, physics, etc.



NASA's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
or
NASA's Hyperion satellites

Image compression

- Lossless vs lossy
- Progressive vs sequential
- Video vs still image
- Several standards: MPEG, H26X, JPEG2000, JPEG-LS, PNG, GIF, JPEG...



Example: JPEG image coding standard

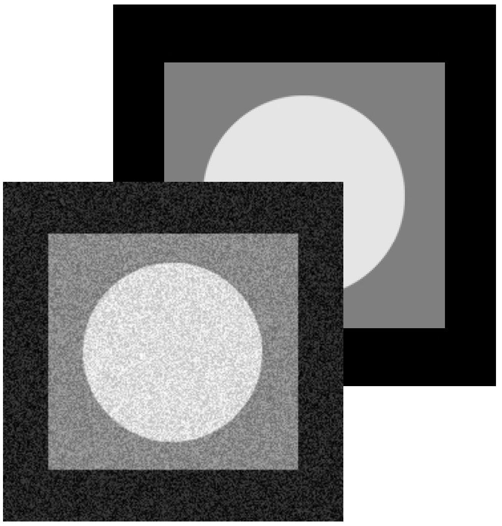
Example JPEG compression

Topic: Noise

- Color spaces
- Color processing
- Noise

Bring the Noise

- Noise is a distortion of the measured signal.
- Every physical system has noise.
- Images:
  - The importance of noise is affected by our human visual perception
  - Ex: Digital TV ‘block effect’ due to noise.



Where does it come from?

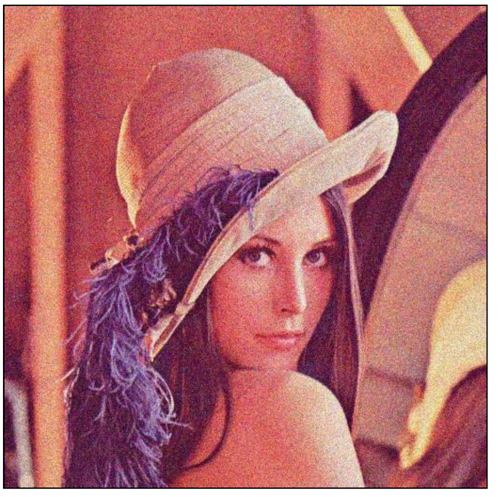
- 'Universal' noise sources:
  - Thermal, sampling, quantization, measurement.
- Specific for digital images:
  - The number of photons hitting each images sensor is governed by quantum physics: *Photon Noise.*
  - Noise generated by electronic components of image sensors:
    - *On-Chip Noise*, *KTC Noise*, *Amplifier Noise*, etc.

Noise Models

- Noise models
  - We need to mathematically handle noise.
  - Spatial and frequency properties.
  - Probability theory helps!
- Advantages:
  - Easier to filter noise.
  - Easier to measure its importance.
  - More robust systems!

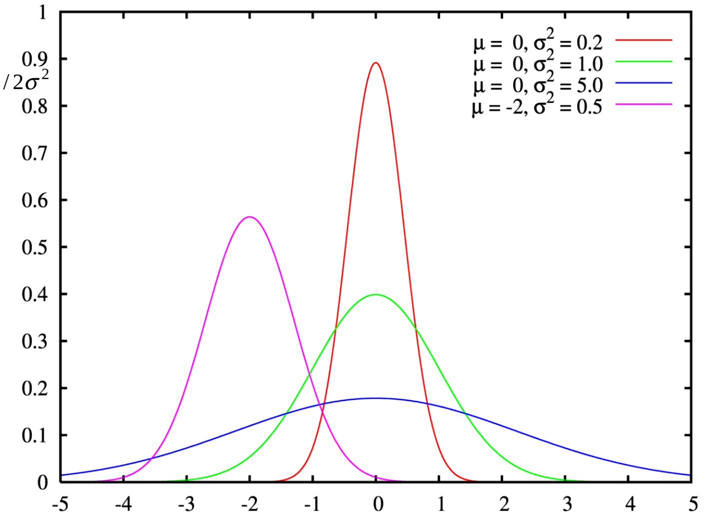
Model: Gaussian Noise

- Gaussian PDF (Probability Density Function).
- Great approximation of reality.
  - Models noise as a sum of various small noise sources, which is indeed what happens in reality.



Model: Gaussian Noise

$$p(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(z-\bar{z})^2/2\sigma^2}$$

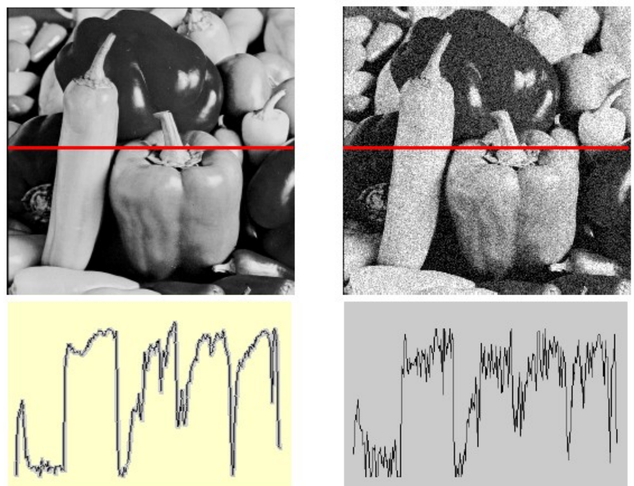


Model: Salt and Pepper Noise

- Considers that a value can randomly assume the MAX or MIN value for that sensor.
  - Happens in reality due to the malfunction of isolated image sensors.

Noise: Profile analysis

Image Noise



$$f(x,y) = \overbrace{\hat{f}(x,y)}^{\text{Ideal Image}} + \overbrace{\eta(x,y)}^{\text{Noise process}}$$

Gaussian i.i.d. ("white") noise

$$\eta(x,y) \sim \mathcal{N}(\mu,\sigma)$$

How do we handle it?

- Not always trivial!
  - Frequency filters.
  - Estimate the degradation function.
  - Inverse filtering.
  - ...

One of the greatest challenges of signal processing!

Resources

- Gonzalez & Woods – Chapters 5 and 6
- http://www.howstuffworks.com/
- http://www.spacetelescope.org