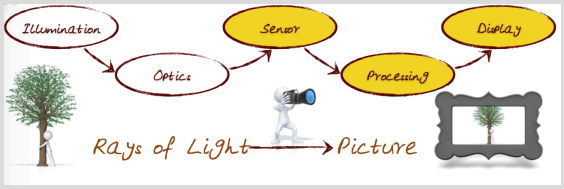
Computational Photography

CS 4475/6475
Maria Hybinette

The Digital Image

- What is a Digital Image?
- How to Make an Image a Computable Entity
- Convert 3D Scene to a 2D

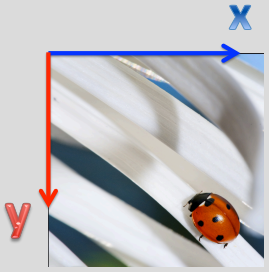


- **Today: How the digital information of the sensor can be used to generate a representation that we can image process**

Objectives

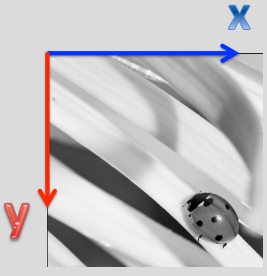
- Digital Image - pixels and image resolution
- Discrete (matrix) and Continuous (function) representations
- Grayscale and Color Images
- Digital Image formats

A Digital Image (W X H)



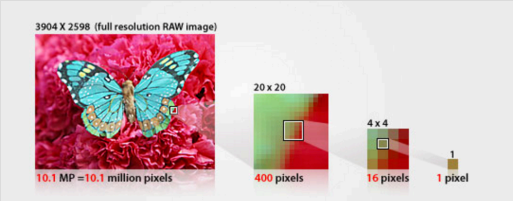
- Width and Height
- Example:
  512 x 512
  262,144 pixels
  0.26 MP Image

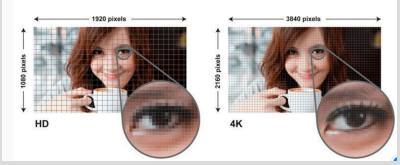
A Digital Image (W X H)



- Numeric representation in 2-D (x and y)
  Referred to as *I(x,y)* in continuous function form, *I(i,j)* in discrete
- Image Resolution: expressed in terms of Width and Height of the image

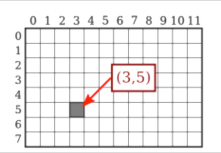
Resolution



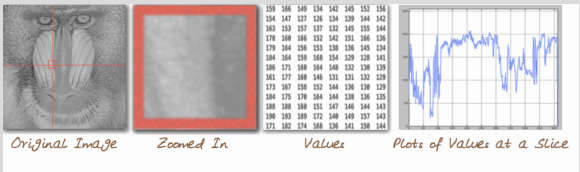


Pixel

- A "picture element"that contains the light intensity at some location
- *(i,j)* in the image



Characteristics of a Digital Image

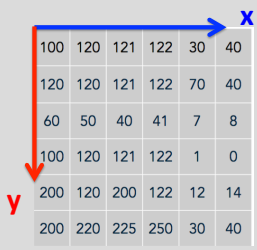


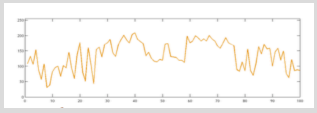
- A two-dimensional array of pixels and respective intensities
- Image can be represented as a Matrix
  Intensity Values range from 0 = Black to 255 = White

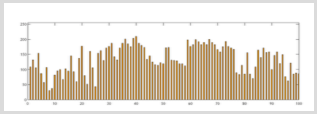
Common data types

- Data types used to store pixel values:
  - unsigned char
  - Uint8
  - unsigned char 8bit
  - 2^n (2^1, 2^2, … 2^8) [2^8 = 256]

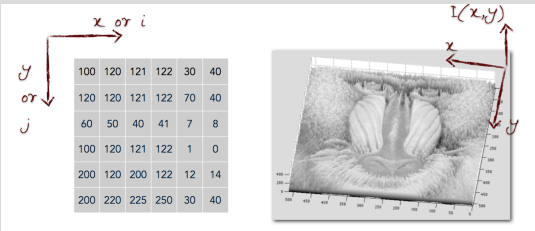
Digital Image is a Function







Digital Image is a Function



- Typically, the functional operation requires discrete values
  Sample the two-dimensional (2D) space on a regular grid
  Quantize each sample (rounded to "nearest integer")
- Matrix of integer values (Range: 0-255)

Black/White Digital Image: An Example

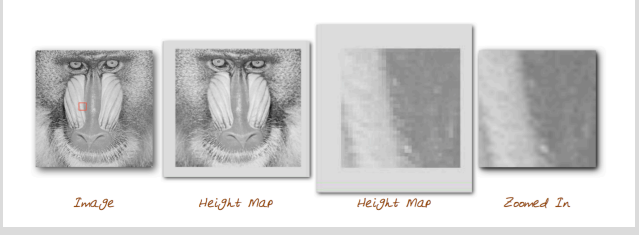
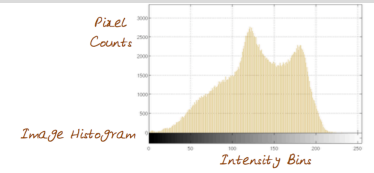
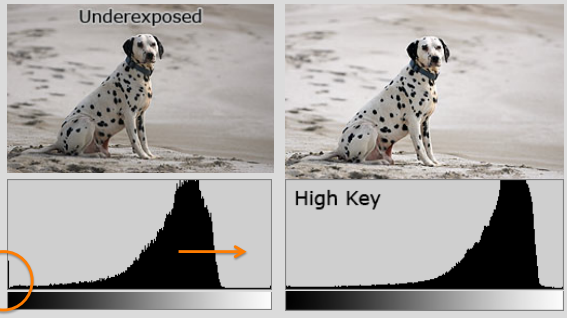


Image Statistics

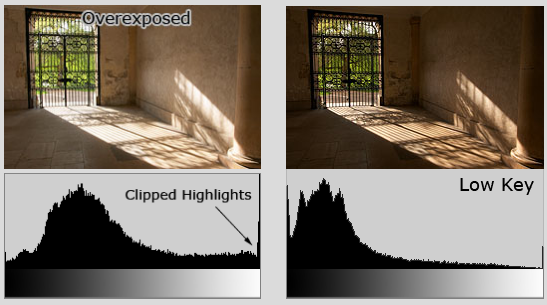


- Digital Image Statistics
- Pixel Counts
- Image Histogram
- Image statistics - average, median, mode
  Scope - entire image or smaller windows/regions
- Histogram - distribution of pixel intensities in the image
- Can be separate for each channel, or region-based too

Histogram

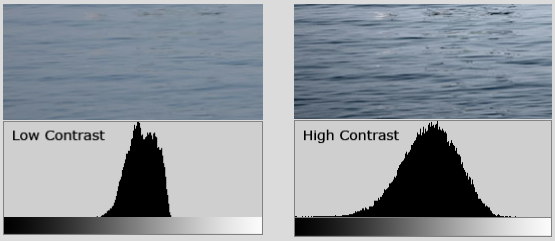


- Underexposed originally left (made it grey)
- Corrected on the right



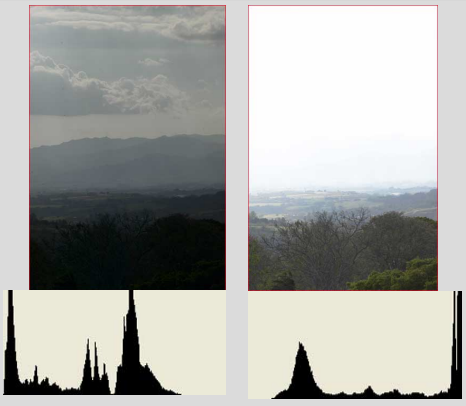
- Overexposed: clipped/blown channels

Contrast

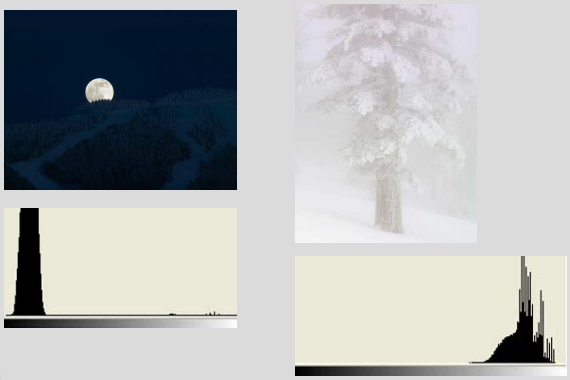


- Narrow range low contrast e.g., (fog no texture on the left)
- Broad range, high contras e.g., (texture water with a range of tones).

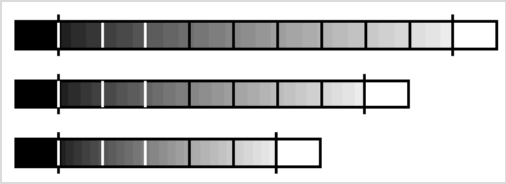
Impossibilities



Bad Histograms?



How much latitude in Camera?



- Nine stops (each stops is double in brightness from its neighbor) contrast range, plus all black and all white
  - (12 stops Hasselblad, 10 stops Nikon D3X)
- Seven stop contrast range, plus all black and all white
- **Five stop** contrast range, plus all black and all white

http://www.forphotography.com/how-tos/zone/zone1.html

Color Digital Image: An Example

- Color image = 3 color channels (images, with their own intensities) blended together
- Makes 3D data structure of size: Width X Height X Channels
  Each pixel has therefore 3 intensities: Red (R), Green (G), Blue (B)

Digital Image Formats

- Raster image formats store a series of colored dots "pixels"
- Number of bits for each pixel represents the depth of color
  - 1 bit-per-pixel: 2 colors (black or white, binary)
  - 4 bits-per-pixel: 16 colors
  - 8 bits-per-pixel: **256 different colors** {2^8}
    - One per channel {24 bits} {8+8+8}
      - Usually means 8 bits per color

Digital Image Formats

- Images can also be 16, 24, 32 bits-per-pixel:
- 24 bits per pixel usually means 8 bits per color
- At the two highest levels, the pixels themselves can carry up to 16,777,216 different colors

- Common raster image formats:
- GIF, JPG, PPM, TIF, BMP, etc.
- Will discuss Camera RAW format later

Exercise

- Read and Write Image
- import cv2
- img = cv2.imread('input.png')
- cv2.imwrite('output.png', img)
- print cv2img
- cv2greyimg = cv2.cvtColor(cv2img, cv2.COLOR_RGB2GRAY)
- print cv2greyimg
- width = data_array.shape[1]

- **Break** then we will go over
  - Point processes (we will use slides from last year0

Wednesday

- Blend Modes
- Image Smoothing
- Start on Image Filters

Part 2: Image Processing and Filtering

- Pont-process Computations on an Image
- How to combine intensities from 2 images?

Lesson Objectives

- Point-process Computations:
- Add/Subtract Images
- α-blending & its applications
- Image Histograms

Review: Digital Image

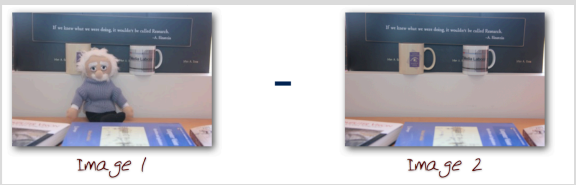
- How to obtain discrete values?
  Sample the two-dimensional (2D) space on a regular grid Quantize each sample (round to "nearest integer")
- Result: Matrix of integer values (range, e.g.: 0-255)

Arithmetic Practice

120	122	140	142	143	+	120	122	140	142	143	=	240	244	280	284	286
121	120	141	144	147		121	80	40	144	10		121	200	181	288	157
122	121	144	146	11		122	81	40	0	151		122	202	184	146	162
125	121	144	145	10		125	80	40	0	152		125	201	184	145	164
126	121	145	147	13		126	70	40	0	153		126	191	185	147	166
120	122	140	142	143	-	120	122	140	142	143	=	0	0	0	0	0
121	120	141	144	147		121	80	40	144	10		0	40	101	0	137
122	121	144	146	11		122	81	40	0	151		0	40	104	146	-140
125	121	144	145	10		125	80	40	0	152		0	40	104	145	-142
126	121	145	147	13		126	70	40	0	153		0	191	185	147	-140

- On the data structure

Pixel/Point Arithmetic: An Example



- Subtraction
- Binary Result

Pixel Operations: Another Example

- 3 Images Added Together
- Step 1. Too bright
- Step 2. Weigh (normalize) their contribution to the final image

Alpha Blending

- .34 x CD+.34 x AE+.34 x LD=
- Transparency (Conversely, Opacity!)
  Usually represented as: **α**
  α varies from 0 to 1.0 (0=invisible, 1.0=fully visible)
- RGB ➔ **α**RGB

Part 3:

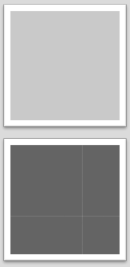
- Blend two pixels from two images
- Examples
  - averages
    - $f_{blend}(a,b) = (a+b)/2$
    - $f_{blend}(a,b) = b$
      - Top layer in photoshop or gimp

Blending Modes (simple)

- **Divide** ('standardize) pixel value first to be between [0, 1] ➔ 0 (black, 0) – 1(white, 255)
  - Brightens photos if standardized, otherwise it would darken.
- **Addition** (too many whites)
- **Subtract** (too many blacks)
- **Difference** (subtract with scaling)
- **Darken**: $f_{blend}(a, b) = \min(a, b)$ for RGB
- **Lighten**: $f_{blend}(a, b) = \max(a, b)$ for RGB

Advanced Modes

- Photoshop uses standardized numbers
  White (255) becomes 1, black (0) is 0
  - **.80 (light gray)**
  - .50 (middle gray)
  - .40 (dark gray)
- **Multiply** $f_{blend}(a,b) = ab$
  - .8*.8 = .64 darker than original
  - .4*.4 = .16 darker
- **Screen** $f_{blend}(a,b) = 1 - (1-a)(1-b)$
  - brighter f(**.8**,.8) = 1 - **(.2)(.2)** = **1-.04= .96**



Advanced Modes

- **Overlay** $f_{blend}(a, b) = \begin{cases} 2ab & \text{if } a < 0.5 \text{ (dark)} \\ 1 - 2(1-a)(1-b) & \end{cases}$
  - Top looks like "multiply" (when **a < .5,** darker than middle gray), and
  - "screen" when a is greater (or brighter than middle gray).
  - Pulls the values further away from middle gray.
  - Recall **0 is black** .5 grey and 1 is white when standardized.

Commuted Blend Model

- Apply the 'other blend mode' in reveres order you get the same result.
- Overlay and Hard Light
  - Overlay(a, b) = HardLight (b, a)
- Luminosity and Color
  - Luminosity(a, b) = HardLight (b, a)

Other Modes for Reference

Darkens:

- Burn Tool darkens an area without affecting saturation or color (different from the below modes).
- Color Burn $f_{blend}(a,b) = 1-(1-b)/a$ (SP8)
- Linear Burn $f_{blend}(a,b) = a+b-1$ (SP8)

Lightens:

- Dodge Tool: Ligthens specified area different from below modes.
- Color Dodge $f_{blend}(a,b) = b/(1-a)$ (SP8)
- Linear Dodge $f_{blend}(a,b) = a+b$ (SP8)

http://photoblogstop.com/photoshop/photoshop-blend-modes-explained

Sources & Inspiration

Contributors of Course Material:

- **Irfan Essa** & Frank Dellaert (Georgia Tech)
  - Also early adopters
- Marc Levoy (Stanford)– taught computational photography since 2002:
  - A leader in the field : Frankecamera
- Frédo Durand (MIT)
- Jack Tumblin (Northwestern)
- Wikipedia
- http://www.all-art.org/history658_photography1.html
- "Photography", London, Stone, Upton