Introducing Assignment 1: Image Processing

COS 426: Computer Graphics (Spring 2021)

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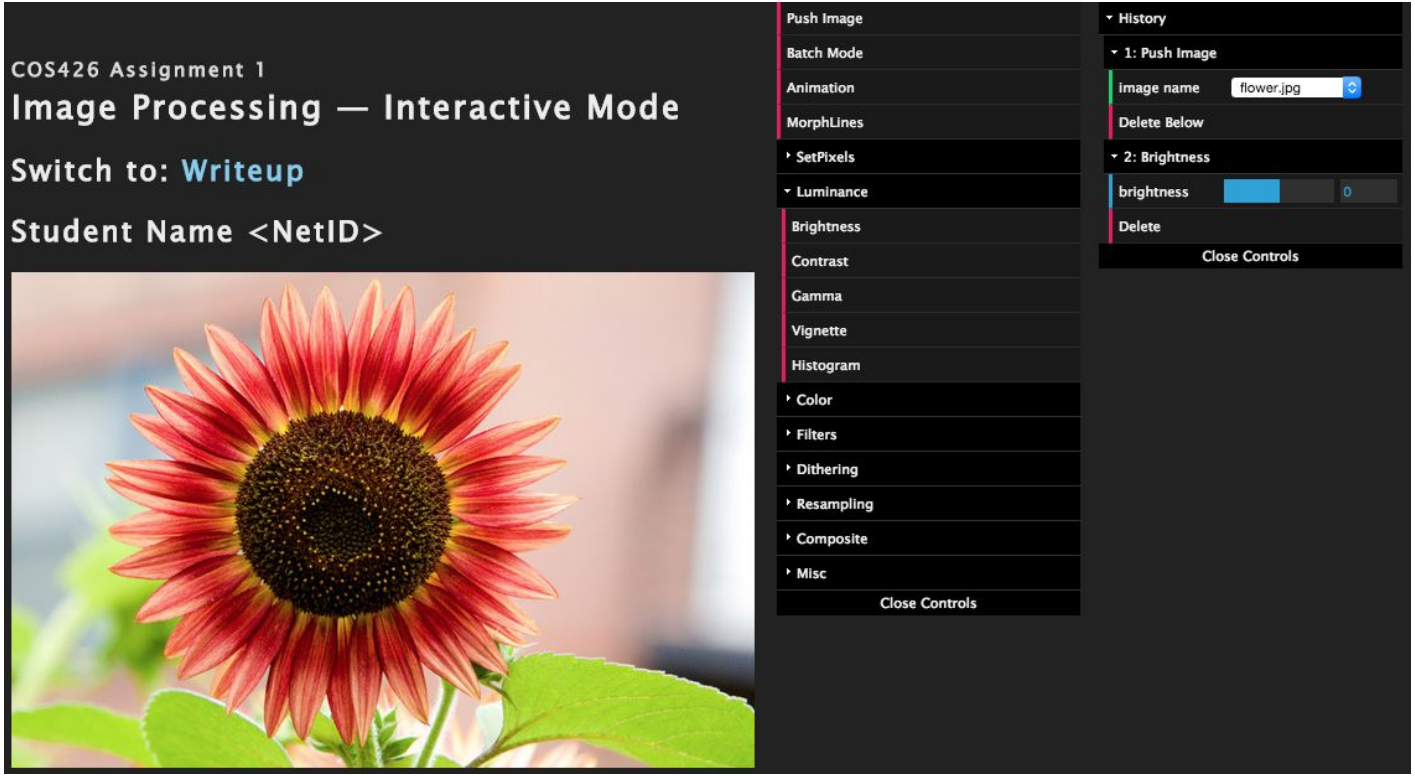
Setup

Same layout as A0:

- Run "`python3 -m http.server`" (or similar) inside the assignment directory
- Open "`http://localhost:8000`" in web browser

GUI


COS426 Assignment 1
Image Processing — Interactive Mode
Switch to: Writeup
Student Name <NetID>
Push Image
Batch Mode
Animation
MorphLines
SetPixels
Luminance
Brightness
Contrast
Gamma
Vignette
Histogram
Color
Filters
Dithering
Resampling
Composite
Misc
Close Controls
History
1: Push Image
image name
flower.jpg
Delete Below
2: Brightness
brightness
0
Delete
Close Controls

GUI

- Useful functions
  - Push Image
  - Animation: generate gif animation using (min, step, max)
  - MorphLines: specify line correspondences for morphing
  - BatchMode: fix current parameter settings

GUI

- Features to implement
  - SetPixels: set pixels to certain colors (This was A0)
  - Luminance: change pixel luminance
  - Color: remap pixel colors
  - Filter: convolution/box filter
  - Dithering: reduce visual artifacts due to quantization ≈ cheat our eyes
  - Resampling: interpolate pixel colors
  - Composite: blending two images
  - Misc

Features

Luminance
- Brightness
- Contrast
- Gamma
- Vignette
- Histogram equalization

Color
- Grayscale
- Saturation
- White balance
- Histogram matching

Filter
- Gaussian
- Sharpen
- Edge detect
- Median
- Bilateral filter

Dithering
- Quantization
- Random dithering
- Floyd-Steinberg error diffusion
- Ordered dithering

Resampling
- Bilinear sampling
- Gaussian sampling
- Translate
- Scale
- Rotate
- Swirl

Composite
- Composite
- Morph

Next week's precept will focus specifically on this topic

A few reminders…

- Don’t try to exactly replicate example images.
- Choose parameters in your code which give you best looking results.
- Have fun!

Changing Contrast

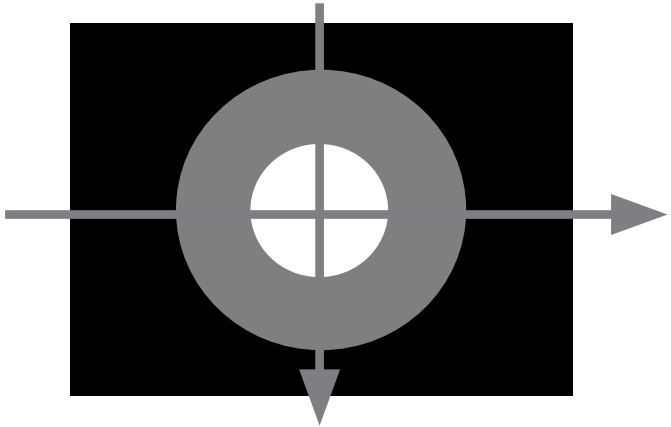
- GIMP formula
  - value = (value - 0.5) * (tan ((contrast + 1) * PI/4)) + 0.5;
  - "Difference above mid-value times contrast multiplier, plus mid-value”
  - When contrast=1, tan(PI/2) is infinite, think about limit and what is reasonable
  - Clamp pixel to [0, 1] after computing the value.
  - Apply to each channel separately.

Gamma correction

- R = R^gamma, G = G^gamma, B = B^gamma
- R,G,B are typically in [0, 1] (default in the code base)
- Second arg of gammaFilter(image, logOfGamma) is log(gamma)
  - So use gamma = Math.exp(logOfGamma)
- Exponentiation in JS is “Math.pow(base, exponent)” or (ES7 / ES2017+) “base**pow”
  - Your browser might not support ES7

Vignette

- Pixels within inner radius remain unchanged
- Pixels outside outer radius are black
- Pixels between innerR and outerR should be multiplied with a value in [0, 1]:
  - Multiplier = 1 - (R - innerR) / (outerR - innerR)
  - R = sqrt(x^2 + y^2) / halfdiag
- Similar to soft brush



Multiplier map

Histogram Equalization

Transform an image so that it has flat histogram of luminance values.

Before

After

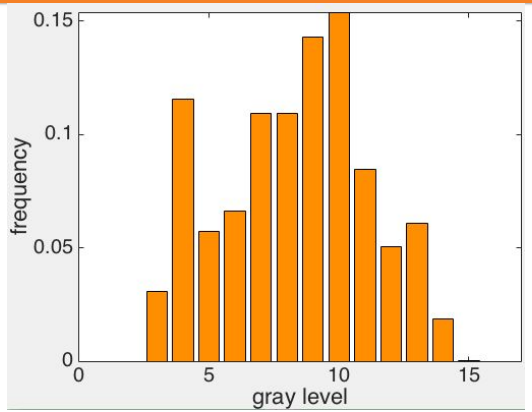
Histogram Matching

Transform an image so that it has same histogram of luminance values as reference image.

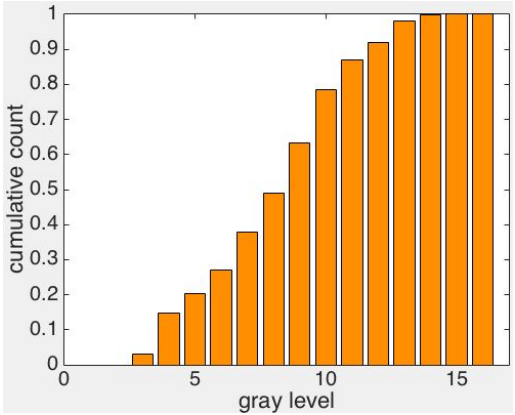
reference image: town

reference image: flower

Histogram Equalization/Matching



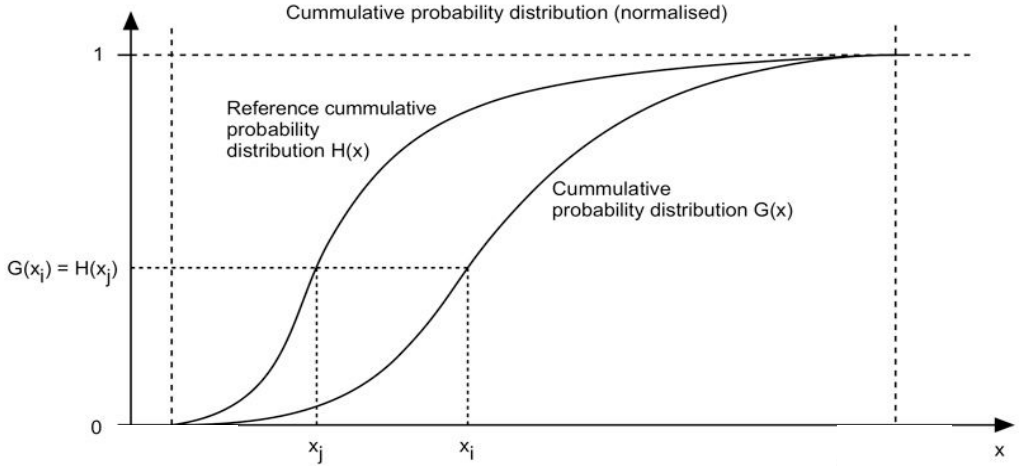
pdf



cdf

Histogram Equalization/Matching

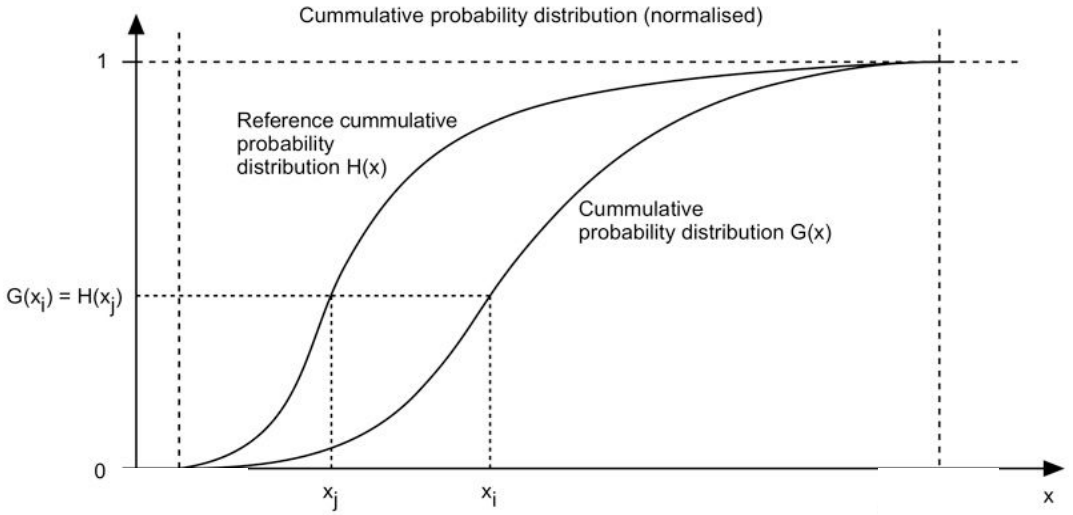
- Image: x
- Number of gray levels: L
- $pdf(i) = \frac{n_i}{n}$ n_i = number of pixels of the i-th gray level
- $cdf(j) = \sum_{j=0}^{i} pdf(i)$
- Target cdf:
  - Equalization:
    - $cdf_{ref}(i) = \frac{i}{L-1}$
  - Matching:
    - cdf of the reference image



(source:http://paulbourke.net/miscellaneous/equalisation/)

Histogram Equalization/Matching

- Target cdf:
  - Equalization:
    - $cdf_{ref}(i) = \frac{i}{L-1}$
  - Matching:
    - cdf of the reference image
- Implementation
  - Equalization
    - $x' = (cdf(x) * (L-1)) / (L-1)$
  - Matching
    - $x' = \arg\min_i |cdf(x) - cdf_{ref}(i)|$
    - Convert back to gray level: $x' = \frac{x'}{L-1}$



Saturation

- pixel = pixel + (pixel - gray(pixel)) * ratio
- Do clamp()

White balance

whitebalance(image, rgb_w)

$[L_w, M_w, S_w]$ = rgb2lms(rgb_w)

for each pixel x in image

[L, M, S] = rgb2lms(image(x))

L = L / L_w

M = M / M_w

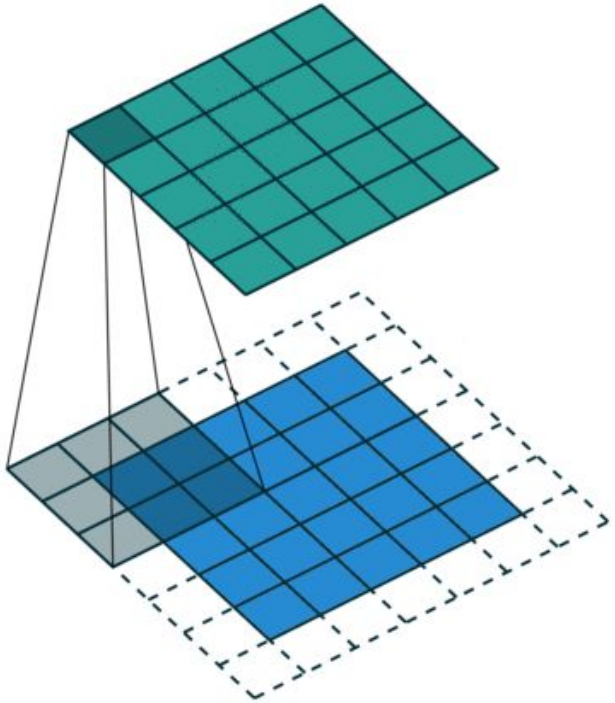
S = S / S_w

image_out(x) = lms2rgb(L, M, S)

- Hints:
  - Use rgbToXyz(), xyzToLms(), lmsToXyz(), xyzToRgb()
  - Do clamp()

Convolution (Gaussian/Sharpen/Edge)

w1	w2	w3
w4	w5	w6
w7	w8	w9



Convolution (Gaussian/Sharpen/Edge)

- Weights can be normalized depending on the application
- Variety of ways to handle edges
  - Mirror boundary
  - Zero padding
  - Use part of the kernel only

Gaussian filter

- Create a new image to work on
- Weights should be normalized to sum to 1, otherwise average color changes

$$G(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2}{2\sigma^2}}$$

$$\frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

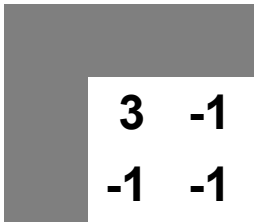
  - x = distance to the center of the kernel
- Linear separation optimization:
  - First apply a 1D Gaussian kernel vertically and then a 1D Gaussian kernel horizontally

Edge

Kernel:

-1	-1	-1
-1	8	-1
-1	-1	-1

Inside boundary



At boundary

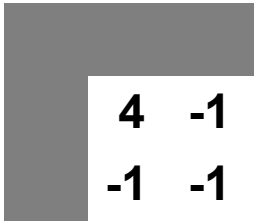
- Weights sum to 0
- Optional to invert the edge map for visualization:
- pixel = 1 - pixel

Sharpen

- Kernel:

-1	-1	-1
-1	9	-1
-1	-1	-1

Inside boundary



4	-1
-1	-1

At boundary

- Weights sum to 1

Edge Filter vs Sharpen Filter

-1	-1	-1
-1	8	-1
-1	-1	-1

Edge Filter

-1	-1	-1
-1	9	-1
-1	-1	-1

Sharpen Filter

Convolution(Image, Sharpen Filter) = Convolution(Image, Edge Filter) + Image

Median

- Use a window (similar to convolution)
- Choose the median within the window
- Sorting: sort by RGB separately / sort by luminance
- Optimization: use quick-select to find median
  - Gives median in linear time

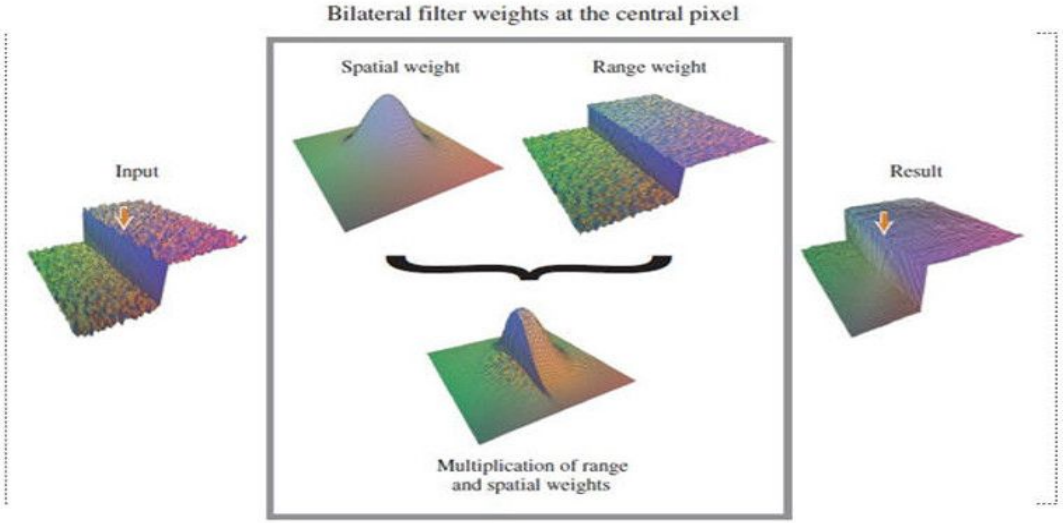
RGB Example

Bilateral

- Combine Gaussian filtering in both spatial domain and color domain
- Weight formula of filter for pixel (i, j): Spatial distance component Color distance component

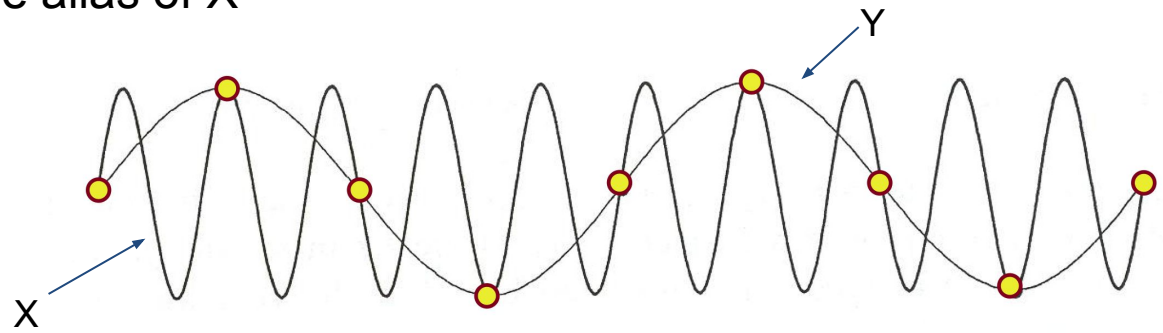
$$w(i,j,k,l) = e^{\left(-\frac{(i-k)^2+(j-l)^2}{2\sigma_d^2} - \frac{\|I(i,j)-I(k,l)\|^2}{2\sigma_r^2}\right)}$$

- Similar color -> large weights, Different color -> smaller weights

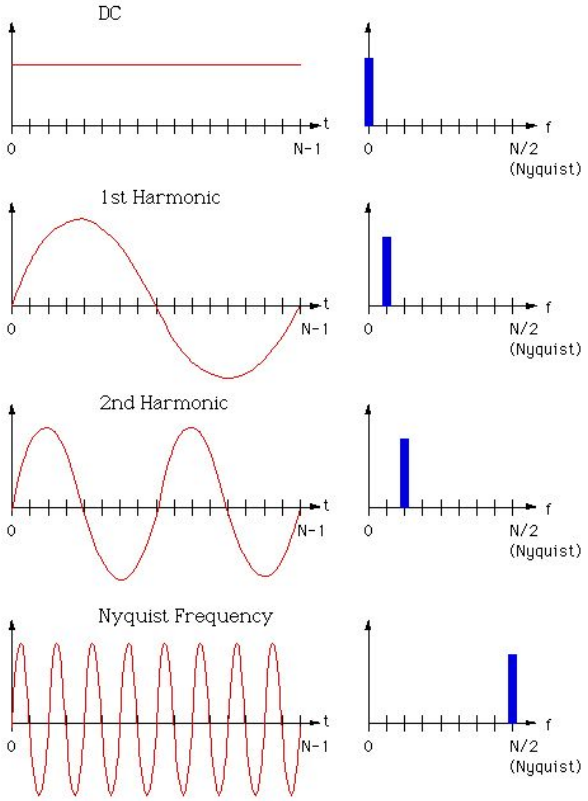


Sampling & Frequencies

- Real-world is continuous, Sensors are discrete
- How many samples do we need to measure real world?
  - Too few samples = aliasing
  - Nyquist rate says that we need to sample at ≥ 2× the highest frequency for perfect reconstruction
- Aliasing is when signal X masquerades as signal Y
  - Y is the alias of X

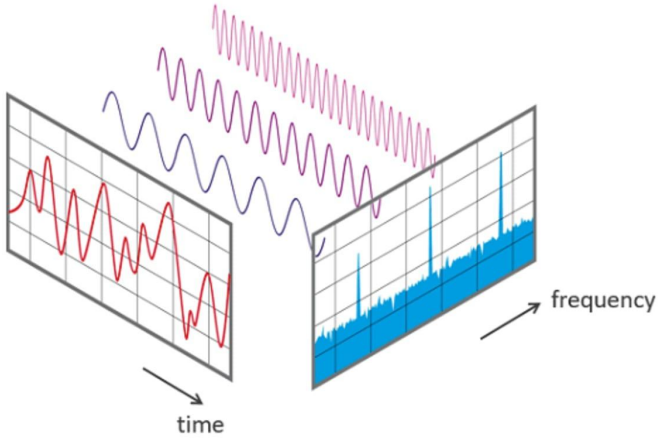


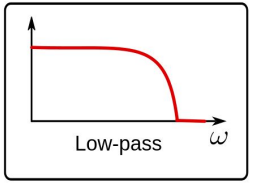
Fourier Transform

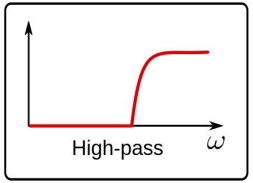


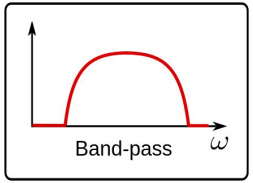
Maps signal from time domain to frequency domain

Use low-pass filter to remove high frequencies and prevent aliasing

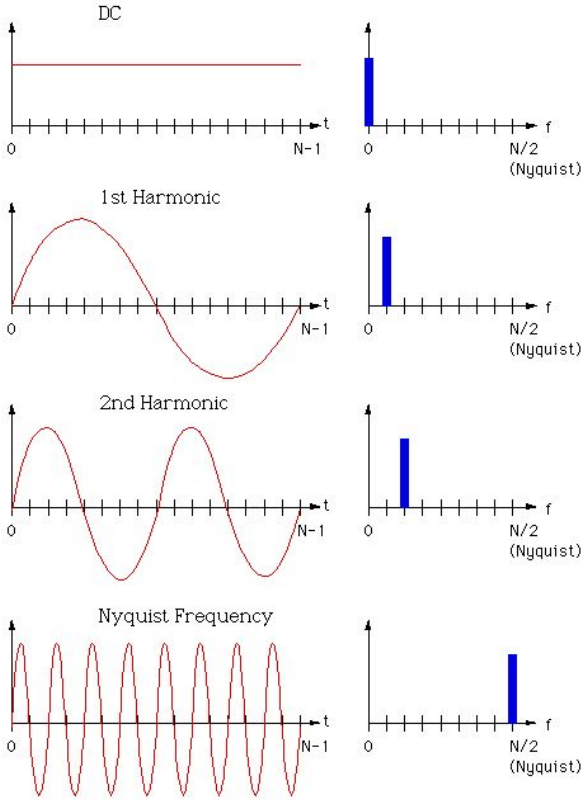








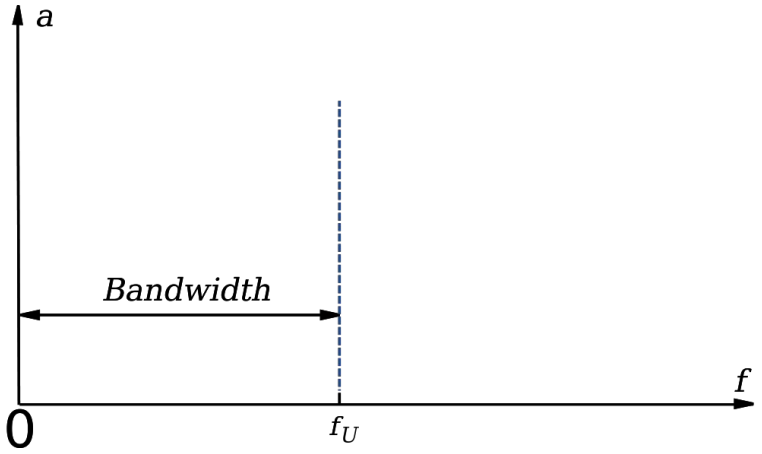
Fourier Transform



Maps signal from time domain to frequency domain

Use low-pass filter to remove high frequencies and prevent aliasing

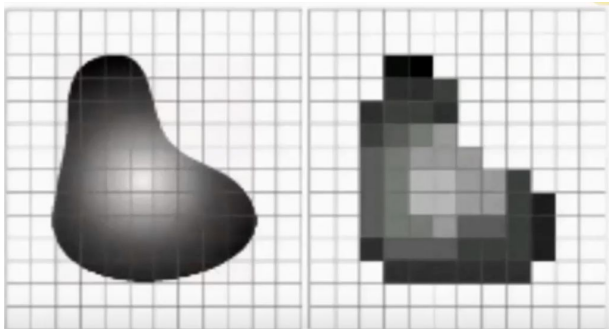
Bandlimiting



1D to 2D

- 2D signals follow the same analysis as 1D signals

Real world 2D image is sampled by sensor



Aliasing for 2D signals

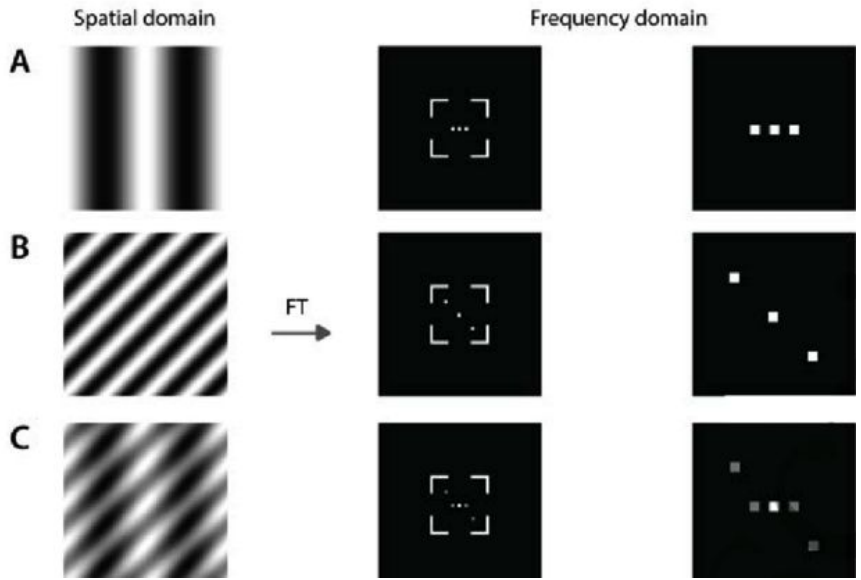
(Barely) adequate sampling

Inadequate sampling

1D to 2D

- 2D signals follow the same analysis as 1D signals

Fourier Analysis for 2D signals



If image resolution is low
- E.g. image compression

Then need to apply band-limiting filter to avoid aliasing
- E.g. Triangle, Gaussian

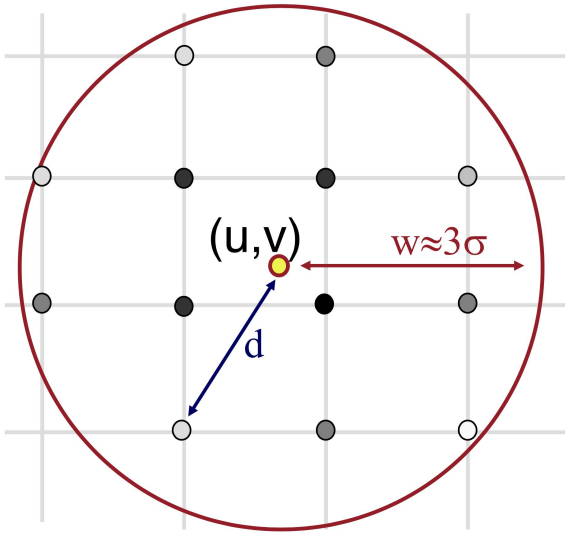
Note that these filters are “finite” filters, they act as approximations to a perfect low pass filter

Resampling

- Gaussian interpolation
  - Weights:

$$G(d,\sigma) = e^{-d^2/(2\sigma^2)}$$

- Weights need to be normalized, so that sum up to 1
- Use windowSize = 3*sigma
  - Sigma can be 1
- Window can be square

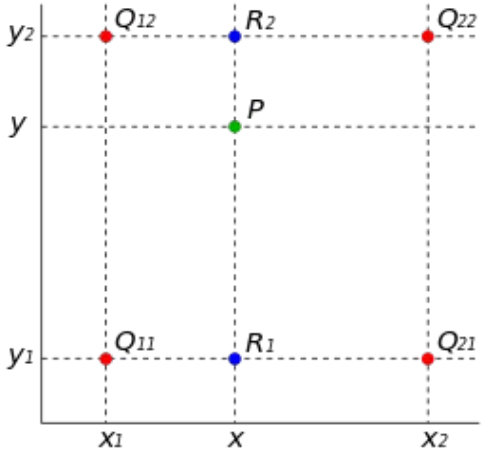


Resampling

- Bilinear interpolation

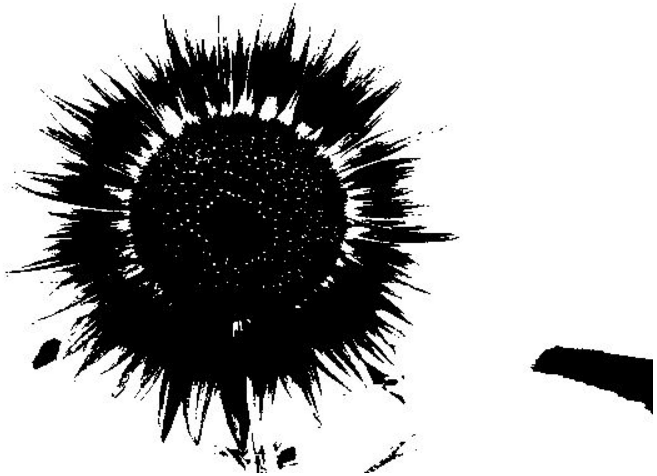
$$f(x,y) = \frac{1}{(x_2-x_1)(y_2-y_1)} (f(Q_{11})(x_2-x)(y_2-y) + f(Q_{21})(x-x_1)(y_2-y) + f(Q_{12})(x_2-x)(y-y_1) + f(Q_{22})(x-x_1)(y-y_1))$$

(from wikipedia)



Quantization

- Quantize a pixel within [0, 1] using n bits
  - round(p * (2^n-1)) / (2^n-1)

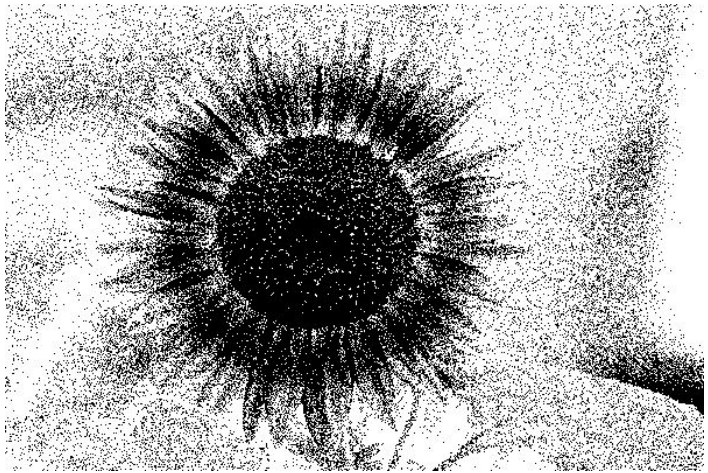


n=1 example

Random dithering

- Before quantization:
  - p = p + (random() - 0.5)/(2^n-1)
  - n is number of bits per channel

Reduce banding with intentional noise



n=1 example

Ordered dithering

Pseudo code for n-bit case:

```
i = x mod m
j = y mod m
err  = I(x, y) - floor_quantize(I(x, y)))
threshold = (D(i, j)+ 1) / (m^2 + 1)
if err > threshold
    P(x, y) = ceil_quantize(I(x, y)))
else
    P(x, y) = floor_quantize(I(x, y)))
```

- floor_quantize(p)
  = floor(p * (2^n-1)) / (2^n-1)
- ceil_quantize(p)
  = ceil(p * (2^n-1)) / (2^n-1)

$$m = 4,\ D = \begin{bmatrix} 15 & 7 & 13 & 5 \\ 3 & 11 & 1 & 9 \\ 12 & 4 & 14 & 6 \\ 0 & 8 & 2 & 10 \end{bmatrix}$$

n=1 example

Floyd-Steinberg error diffusion

- Loop over pixels line by line
  - Quantize pixel
  - Compute quantization error (the difference of the original pixel and the quantized pixel)
  - Spread quantization error over four unseen neighboring pixels with weights (see left figure below)
- Results look more natural