CSCI 420 Computer Graphics

Lecture 22

Image Processing

Blending

Display Color Models

Filters

Dithering

[Ch 6, 7]

Jernej Barbic
University of Southern California

Alpha Channel

- Frame buffer
  - Simple color model: R, G, B; 8 bits each
  - α-channel A, another 8 bits
- Alpha determines opacity, pixel-by-pixel
  - α = 1: opaque
  - α = 0: transparent

checkerboard pattern = opacity

Source: Wikipedia

Blending

- Blend transparent objects during rendering
- Achieve other effects (e.g., shadows)

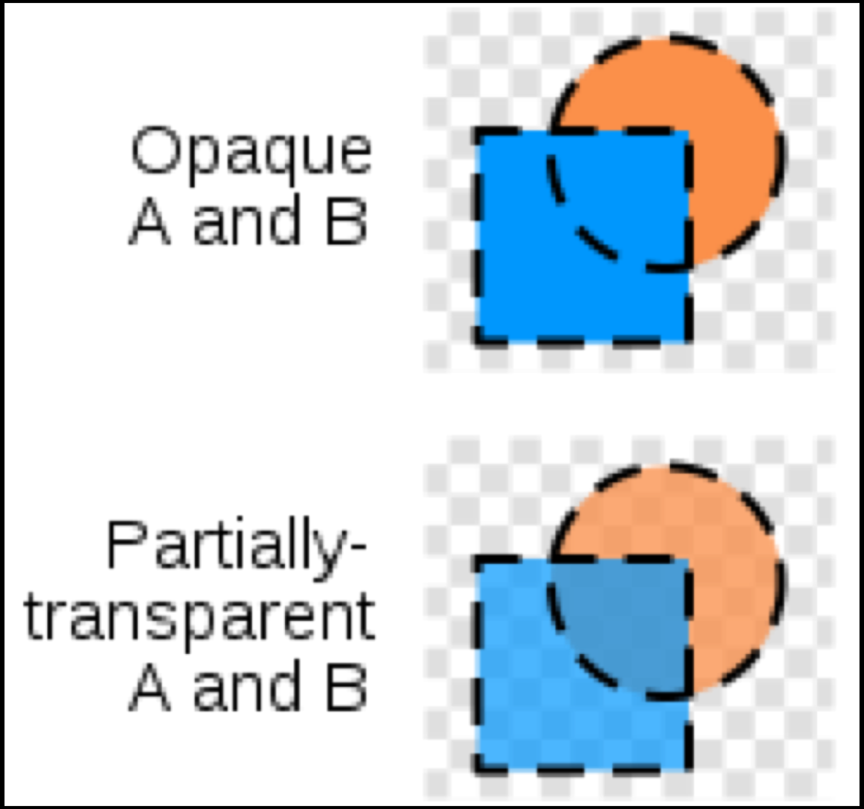

Image Compositing

- Compositing operation
  - Source: $\mathbf{s} = [s_r \;\; s_g \;\; s_{\mathbf{b}} \;\; s_a]$
  - Destination: $\mathbf{d} = [d_r \;\; d_g \;\; d_b \;\; d_a]$
  - $\mathbf{b} = [b_r \;\; b_g \;\; b_b \;\; b_a]$ source blending factors
  - $\mathbf{c} = [c_r \;\; c_g \;\; c_b \;\; c_a]$ destination blending factors
  - $\mathbf{d}' = [b_r s_r + c_r d_r \;\; b_g s_g + c_g d_g \;\; b_b s_b + c_b d_b \;\; b_a s_a + c_a d_a]$
- Example: overlay n images with equal weight
  - Set α-value for each pixel in each image to 1/n
  - Source blending factor is “α”
  - Destination blending factor is “1”

Blending in OpenGL

- Enable blending

  `glEnable(GL_BLEND);`

- Set up source and destination factors

  `glBlendFunc(source_factor, dest_factor);`

- Source and destination choices
  - `GL_ONE, GL_ZERO`
  - `GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA` $\left.\right\}$ common choice
  - `GL_DST_ALPHA, GL_ONE_MINUS_DST_ALPHA`
- Set alpha values: 4th parameter to color (in the VBO)

Blending Errors

- Operations are not commutative
  - rendering order changes result
- Operations are not idempotent
  - render same object twice gives different result to rendering once
- Interaction with hidden-surface removal is tricky
  - Polygon behind opaque polygon(s) should be culled
  - Transparent in front of others should be composited
  - Solution: make z-buffer read-only for transparent polygons with `glDepthMask(GL_FALSE);`

Outline

- Blending
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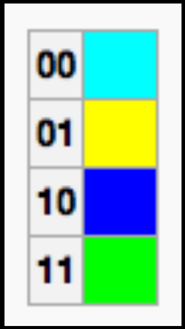
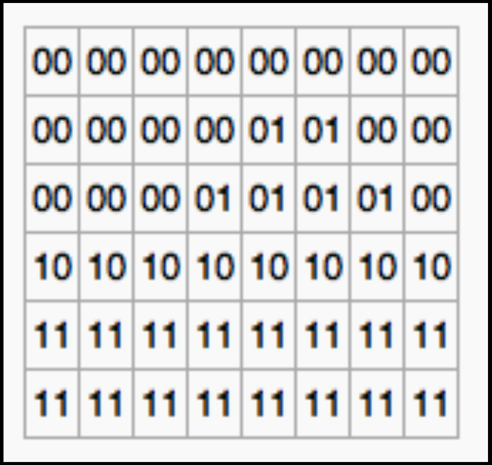
Displays and Framebuffers

- Image stored in memory as 2D pixel array, called framebuffer
- Value of each pixel controls color
- Video hardware scans the framebuffer at 60Hz
- Depth of framebuffer is information per pixel
  - 1 bit: black and white display
  - 8 bit: 256 colors at any given time via colormap
  - 16 bit: 5, 6, 5 bits (R,G,B), 2^{16} = 65,536 colors
  - 24 bit: 8, 8, 8 bits (R,G,B), 2^{24} = 16,777,216 colors

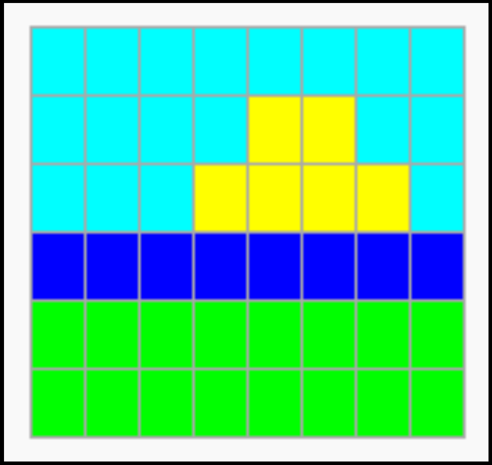
Fewer Bits: Colormaps



00	🟦
01	🟨
10	🟦
11	🟩



00	00	00	00	00	00	00	00
00	00	00	00	01	01	00	00
00	00	00	01	01	01	01	00
10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11
11	11	11	11	11	11	11	11



colormap, k=2

the pixels (indices into colormap)

the image

- Colormap is array of RGB values, k bits each (e.g., k=8)
- Each pixel stores not the color, but an index into colormap
- All 2^{24} colors can be represented, but only 2^k colors at a time
- Poor approximation of full color
- Colormap hacks: affect image without changing framebuffer (only colormap)

More Bits: Graphics Hardware

- 24 bits: RGB
- + 8 bits: A (α-channel for opacity)
- + 16 bits: Z (for hidden-surface removal)
- * 2: double buffering for smooth animation
- = 96 bits
- For 1024 * 768 screen: 9 MB
- Easily possible on modern hardware

Image Processing

- 2D generalization of signal processing
- Image as a two-dimensional signal
- Point processing: modify pixels independently
- Filtering: modify based on neighborhood
- Compositing: combine several images
- Image compression: space-efficient formats
- Other topics
  - Image enhancement and restoration
  - Computer vision

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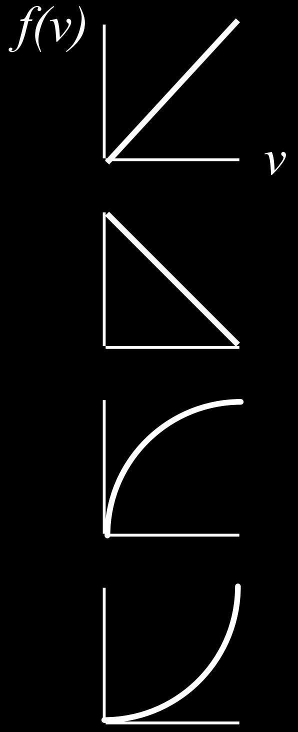
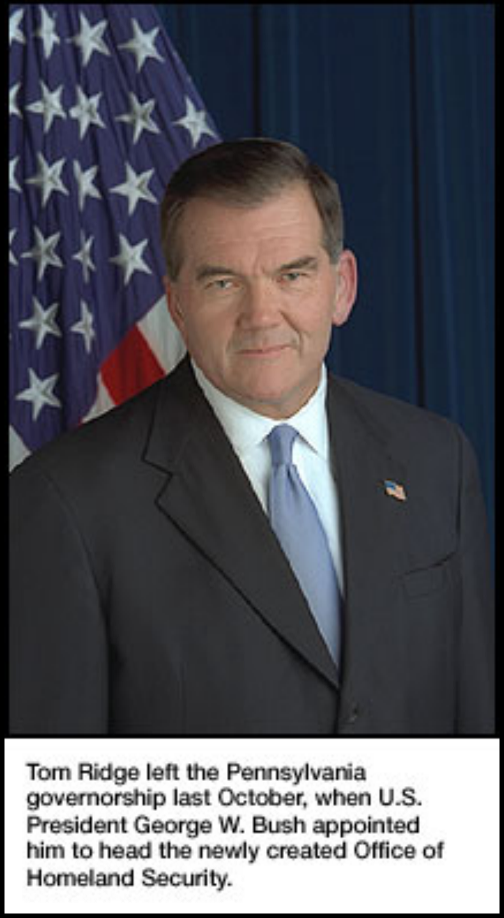
Point Processing

- Process each pixel independently from others
- Input: $a(x,y)$; Output: $b(x,y) = f(a(x,y))$
- Useful for contrast adjustment, false colors
- Examples for grayscale, $0 \le v \le 1$
  - $f(v) = v$ (identity)
  - $f(v) = 1-v$ (negate image)
  - $f(v) = v^p$, $p < 1$ (brighten)
  - $f(v) = v^p$, $p > 1$ (darken)

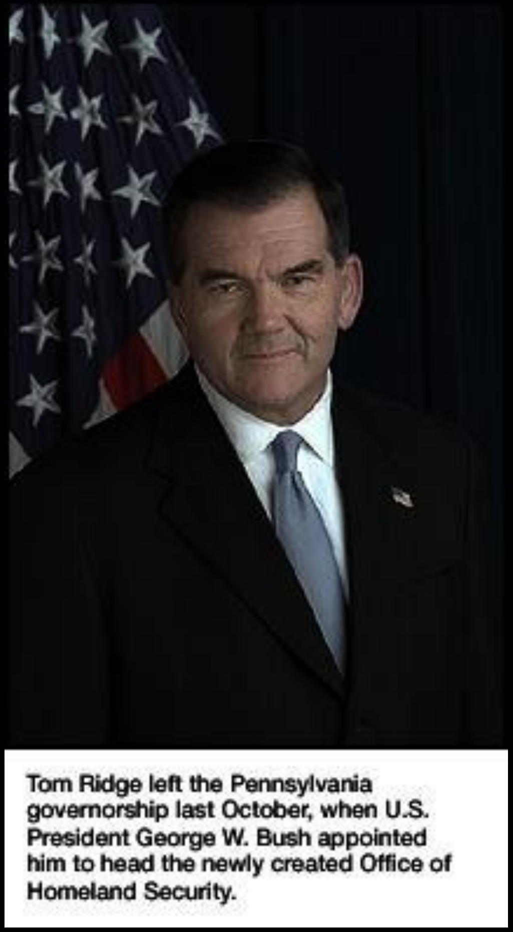


Gamma Correction

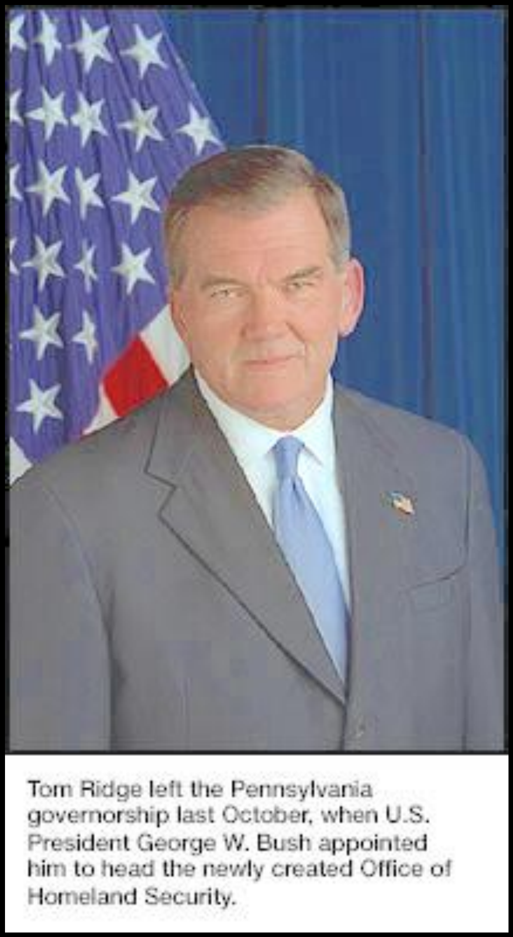
- Example of point processing
- Compensates monitor brightness nonlinearities (older monitors)


Tom Ridge left the Pennsylvania governorship last October, when U.S. President George W. Bush appointed him to head the newly created Office of Homeland Security.

$\Gamma = 1.0;\ f(v) = v$


Tom Ridge left the Pennsylvania governorship last October, when U.S. President George W. Bush appointed him to head the newly created Office of Homeland Security.

$\Gamma = 0.5;\ f(v) = v^{1/0.5} = v^2$


Tom Ridge left the Pennsylvania governorship last October, when U.S. President George W. Bush appointed him to head the newly created Office of Homeland Security.

$\Gamma = 2.5;\ f(v) = v^{1/2.5} = v^{0.4}$

Signals and Filtering

- Audio recording is 1D signal: amplitude(t)
- Image is a 2D signal: color(x,y)
- Signals can be continuous or discrete
- Raster images are discrete
  - In space: sampled in x, y
  - In color: quantized in value
- Filtering: a mapping from signal to signal

Linear and Shift-Invariant Filters

- Linear with respect to input signal
- Shift-invariant with respect to parameter
- Convolution in 1D
  - a(t) is input signal
  - b(s) is output signal
  - h(u) is filter

$$b(s) = \sum_{t=-\infty}^{+\infty} a(t)h(s-t)$$

- Convolution in 2D

$$b(x,y) = \sum_{u=-\infty}^{+\infty} \sum_{v=-\infty}^{+\infty} a(u,v)h(x-u,y-v)$$

Filters with Finite Support

- Filter h(u,v) is 0 except in given region
- Example: 3 x 3 blurring filter

$$\begin{aligned} b(x,y) = \tfrac{1}{9}\Big(& a(x-1,y-1) + a(x,y-1) + a(x+1,y-1) \\ & + a(x-1,y) + a(x,y) + a(x+1,y) \\ & + a(x-1,y+1) + a(x,y+1) + a(x+1,y+1)\Big) \end{aligned}$$

- As function

$$h(u,v) = \begin{cases} \frac{1}{9}; & \text{if } -1 \le u,v \le 1 \\ 0; & \text{otherwise} \end{cases}$$

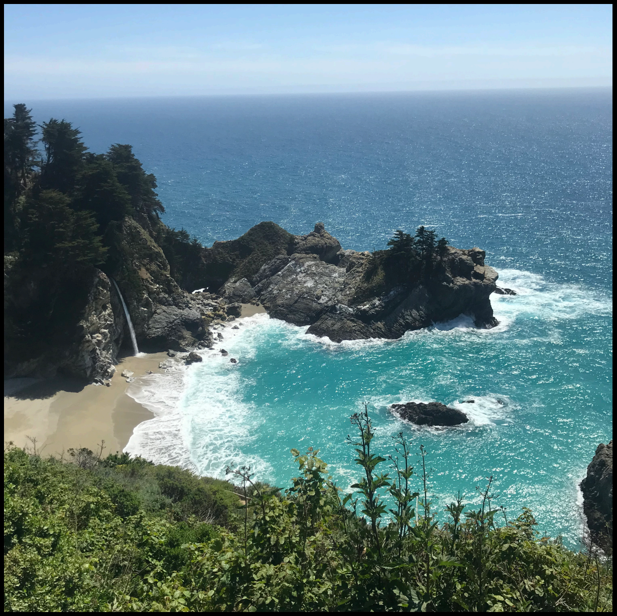
- In matrix form

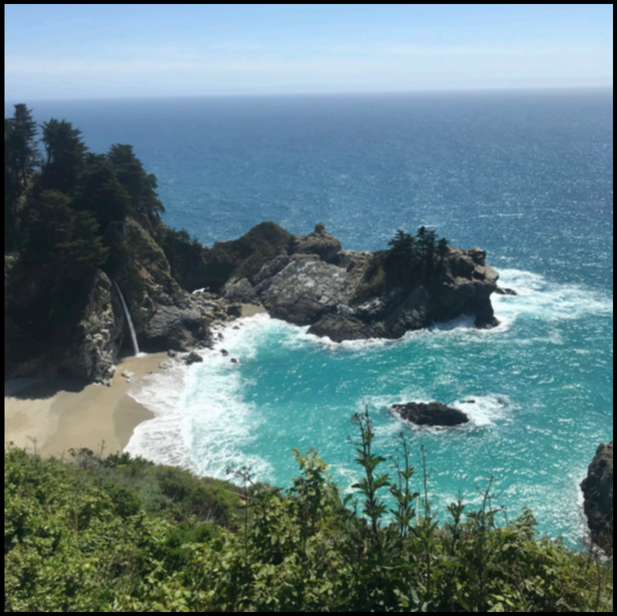
$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

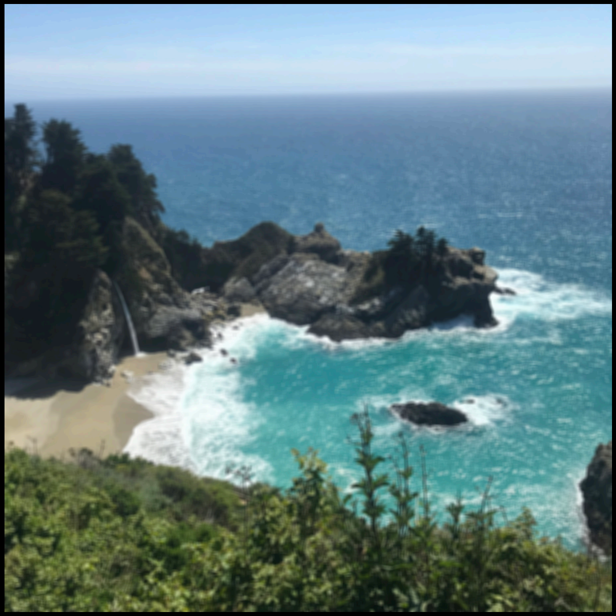
Blurring Filters

- Average values of surrounding pixels
- Can be used for anti-aliasing
- Size of blurring filter should be odd
- What do we do at the edges and corners?
- For noise reduction, use median, not average
  - Eliminates intensity spikes
  - Non-linear filter

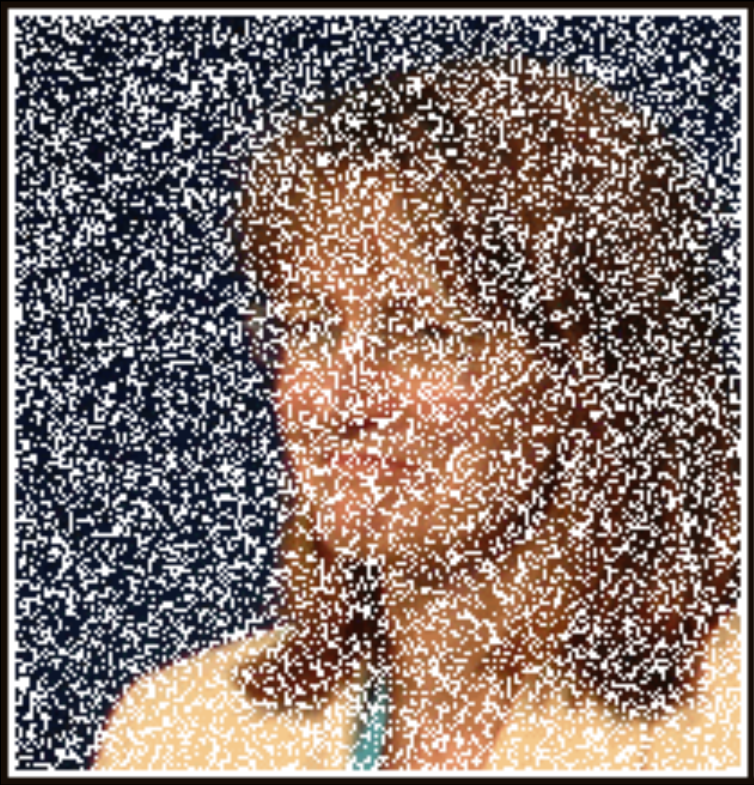
Examples of Blurring Filter


Original Image

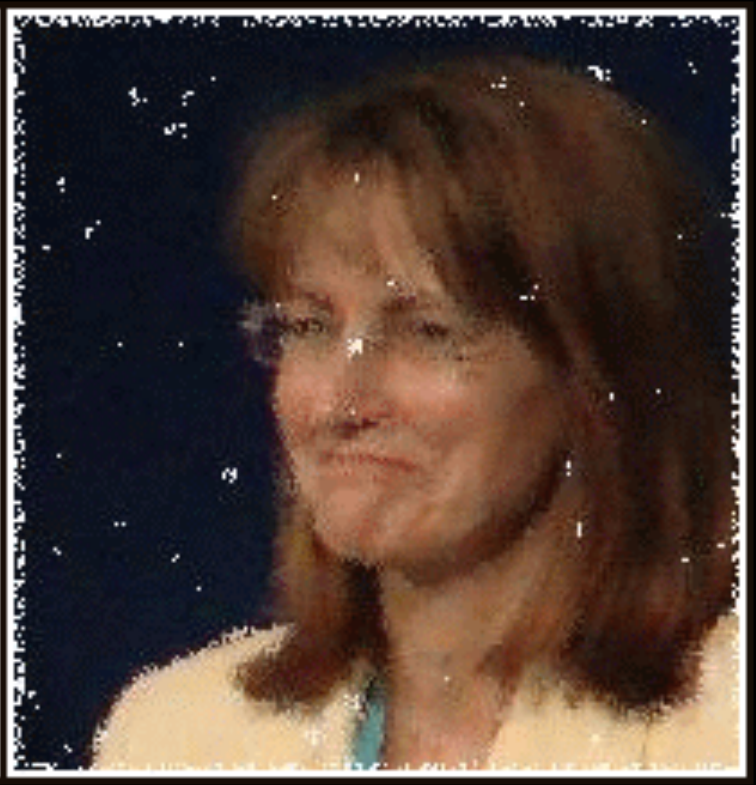

Blur 5x5 mask


Blur 10x10 mask

Noise Reduction with the Median Filter



Input



Output

Source: Wikipedia

Edge Filters

- Task: Discover edges in image
- Characterized by large gradient

$$\nabla a = \left[\frac{\partial a}{\partial x} \quad \frac{\partial a}{\partial y}\right], \qquad |\nabla a| = \sqrt{\left(\frac{\partial a}{\partial x}\right)^2 + \left(\frac{\partial a}{\partial y}\right)^2}$$

- Approximate square root

$$|\nabla a| \approx \left|\frac{\partial a}{\partial x}\right| + \left|\frac{\partial a}{\partial y}\right|$$

- Approximate partial derivatives, e.g.

$$\frac{\partial a}{\partial x} \approx a(x+1) - a(x-1)$$

Sobel Filter

- Very popular edge detection filter
- Approximate:

$$\frac{\partial}{\partial x} \approx \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \qquad \frac{\partial}{\partial y} \approx \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

- Output is |∇a|, computed as follows:

$$\nabla a = \left[\frac{\partial a}{\partial x} \quad \frac{\partial a}{\partial y}\right], \qquad |\nabla a| = \sqrt{\left(\frac{\partial a}{\partial x}\right)^2 + \left(\frac{\partial a}{\partial y}\right)^2}$$

- Sobel filter is non-linear
  - Square and square root (more exact computation)
  - Can also use absolute value (faster computation)

Sobel Filter Computation Example

- Vertical part the Sobel filter
- Detects vertical edges

-1	0	1
-2	0	2
-1	0	1

h

0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20
0	0	0	0	0	20	20	20	20	20

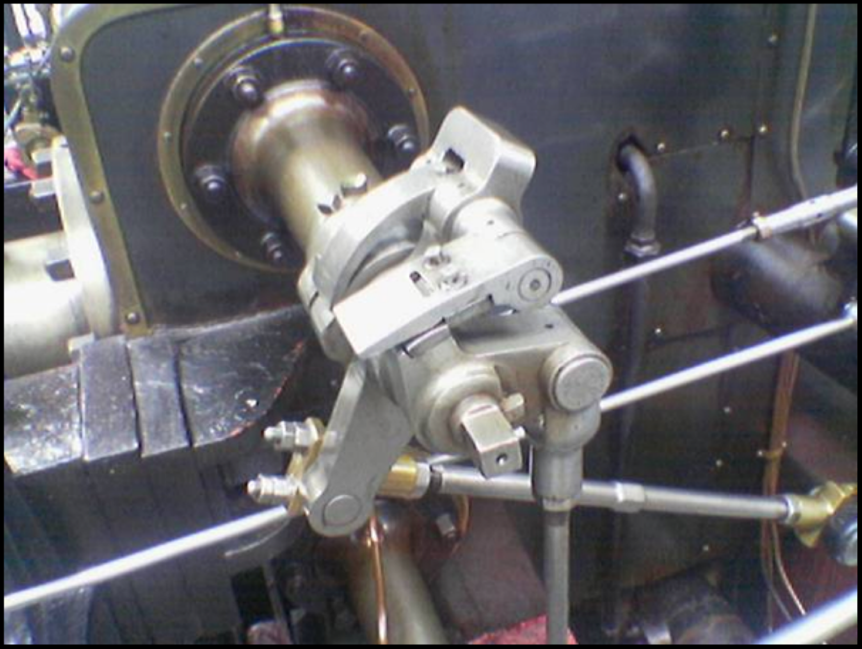
input

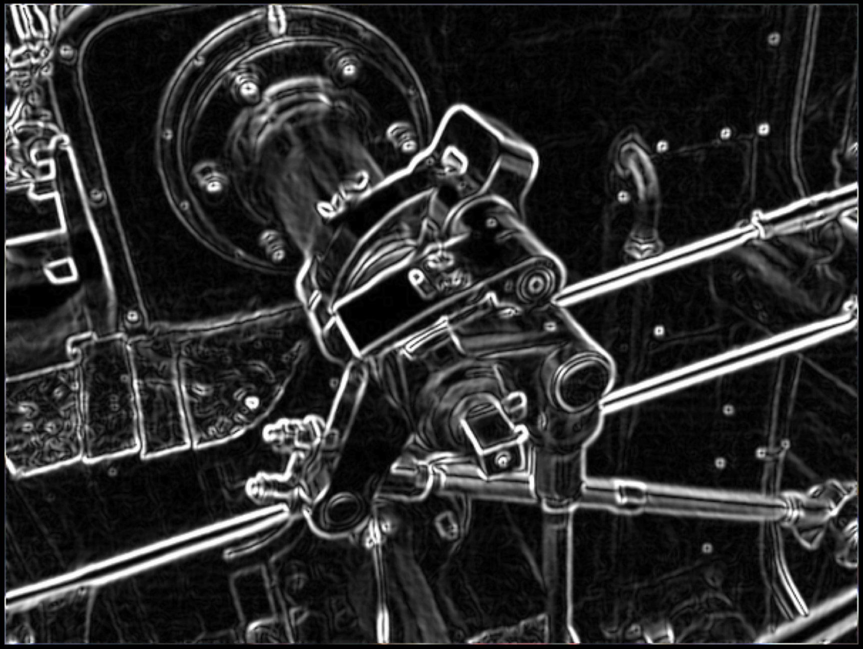
0	0	0	0	60	60	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	80	80	0	0	0	0
0	0	0	0	60	60	0	0	0	0

output

high value = edge

Sobel Filter Example


Input


Output

Source: Wikipedia

Outline

- Blending
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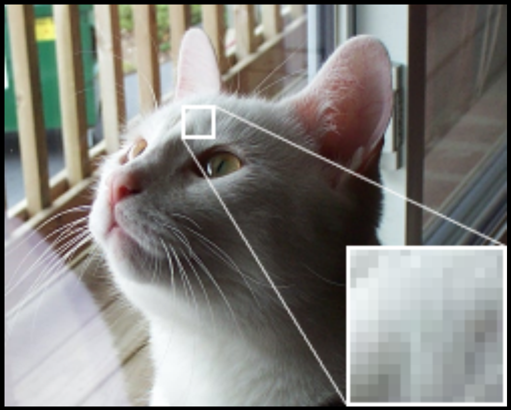
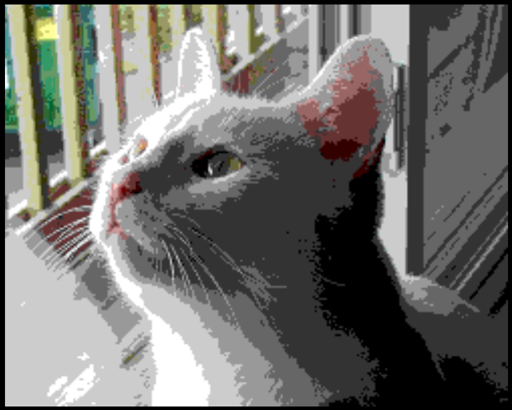
- Dithering

Dithering

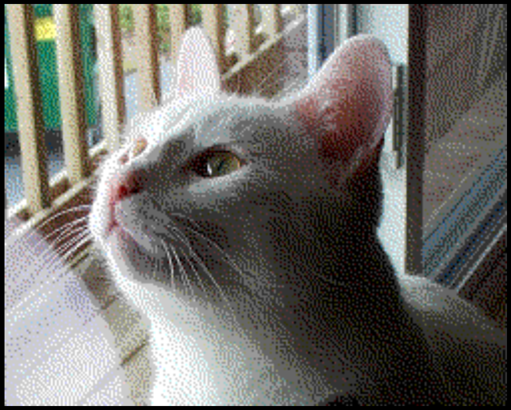
- Compensates for lack of color resolution
- Give up spatial resolution for color resolution
- Eye does spatial averaging



original



web-safe colors, no dithering

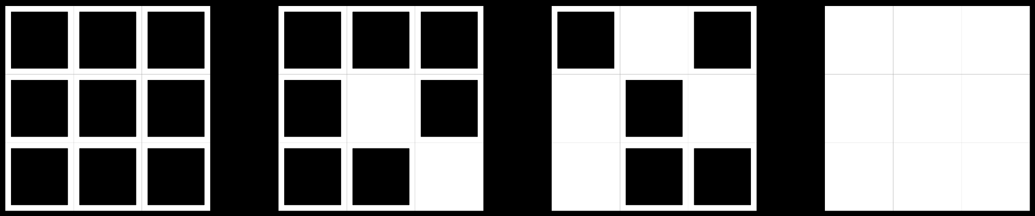


web-safe colors, with dithering

Source: Wikipedia

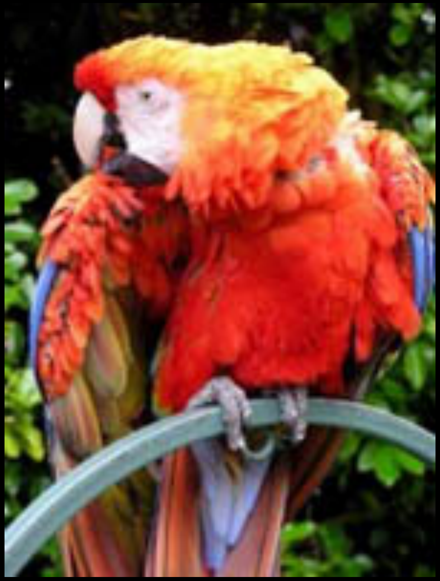
Black/White Dithering

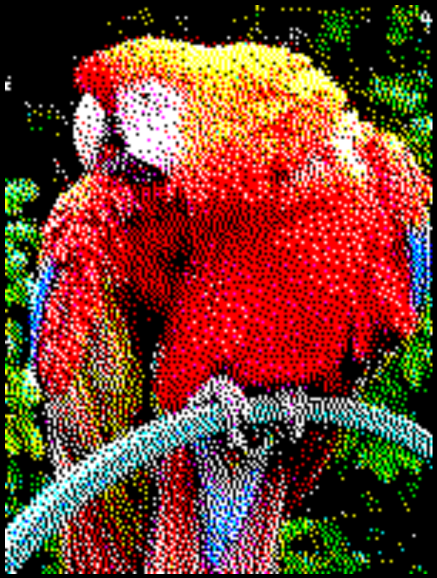
- For gray scale images
- Each pixel is black or white
- From far away, eye perceives color by fraction of white
- For 3x3 block, 10 levels of gray scale



Color Dithering

- Dither RGB separately
- Store quantized color as a k-bit value (often k=8)

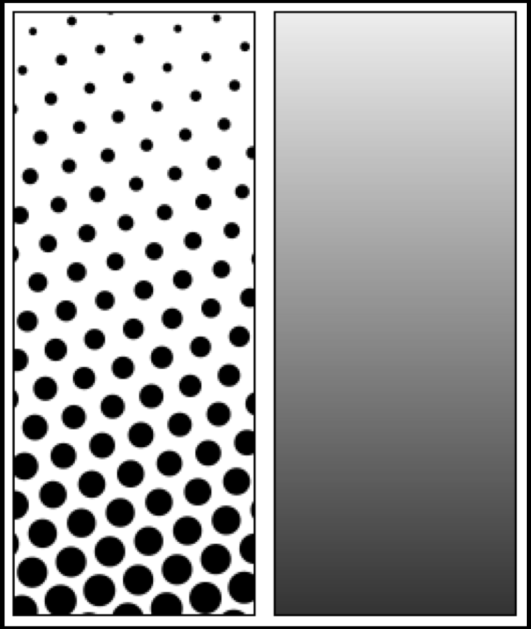

original image
256 colors
per RGB channel


dithered, k=3
only 8 colors
per RGB channel

Source: Wikipedia

Halftoning

- Create grayscale images using properly positioned/sized dots
- Regular patterns create artifacts
  - Avoid stripes
  - Avoid isolated pixels (e.g. on laser printer)
  - Monotonicity: keep pixels on at higher intensities
  - Floyd-Steinberg dithering
- Example of good 3x3 dithering matrix
  - For intensity n, turn on pixels 0..n–1



Source: Wikipedia

$$\begin{bmatrix} 6 & 8 & 4 \\ 1 & 0 & 3 \\ 5 & 2 & 7 \end{bmatrix}$$

Summary

- Display Color Models
  - 8 bit (colormap), 24 bit, 96 bit
- Filters
  - Blur, edge detect, sharpen, despeckle (noise removal)
- Dithering