CSCI 420 Computer Graphics
Lecture 22

Image Processing

Blending
Display Color Models
Filters
Dithering
[Ch 6, 7]

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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
  - $\alpha = 1$: opaque
  - $\alpha = 0$: transparent

checkerboard pattern = opacity

Source: Wikipedia

Blending

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

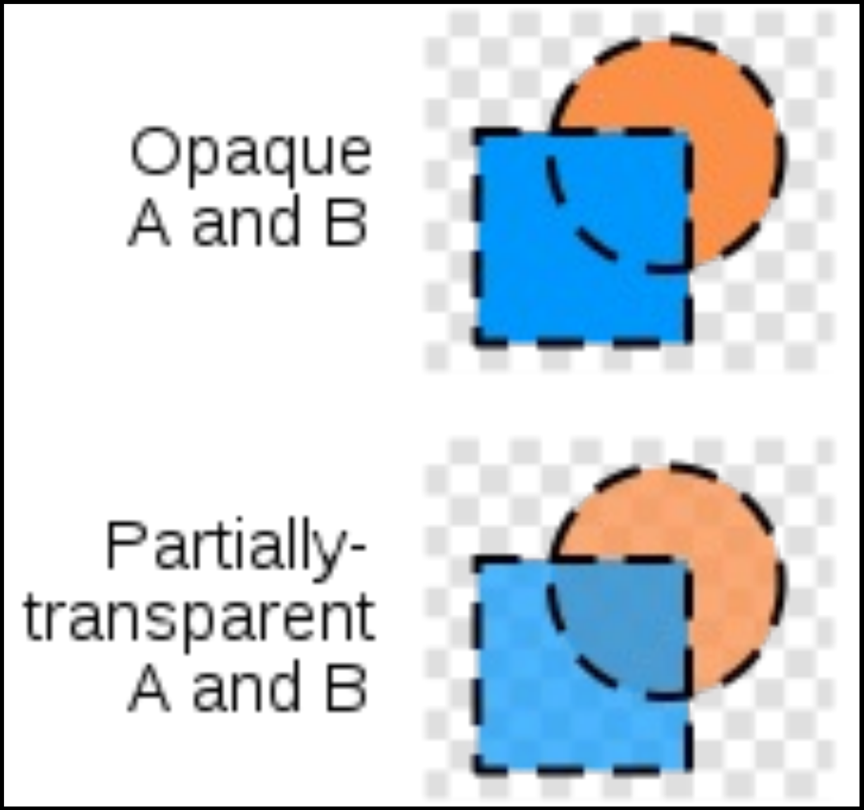


Image Compositing

- 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
  - Source blending factor is $\alpha = 1/n$
  - 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`
  - `GL_DST_ALPHA, GL_ONE_MINUS_DST_ALPHA`

  common choice

- 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);`

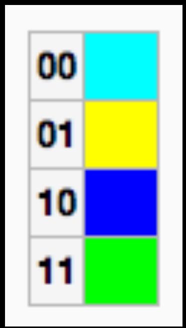
Outline

- Blending
- Display Color Models
- Filters
- Dithering

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

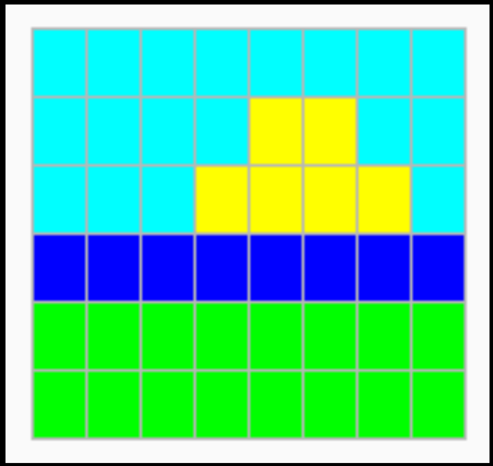
Fewer Bits: Colormaps



colormap,
k=2

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

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 3840 * 2160 screen: 95 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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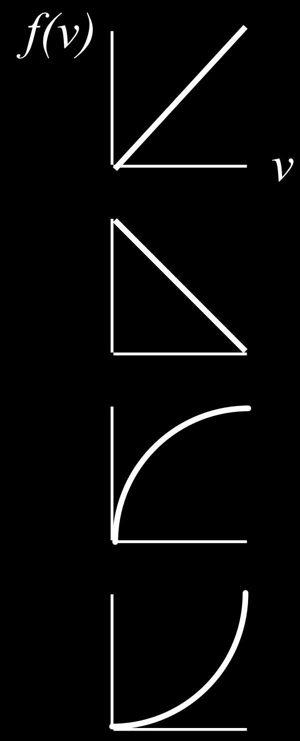
Point Processing

- 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, $0 \leq v \leq 1$
  - $f(v) = v$ (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)

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

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

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

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

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

- As function

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

- 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 $|\nabla a|$, 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 of 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

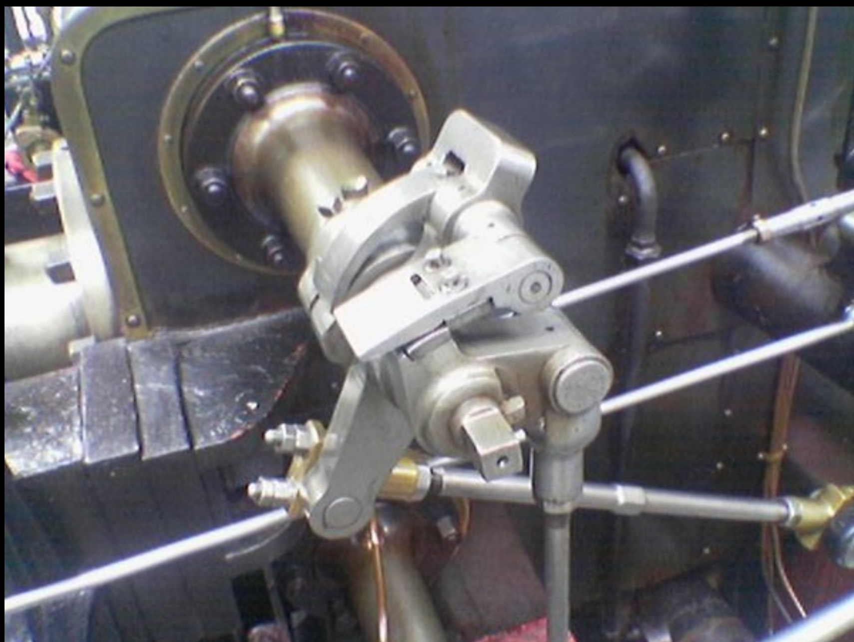
input

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

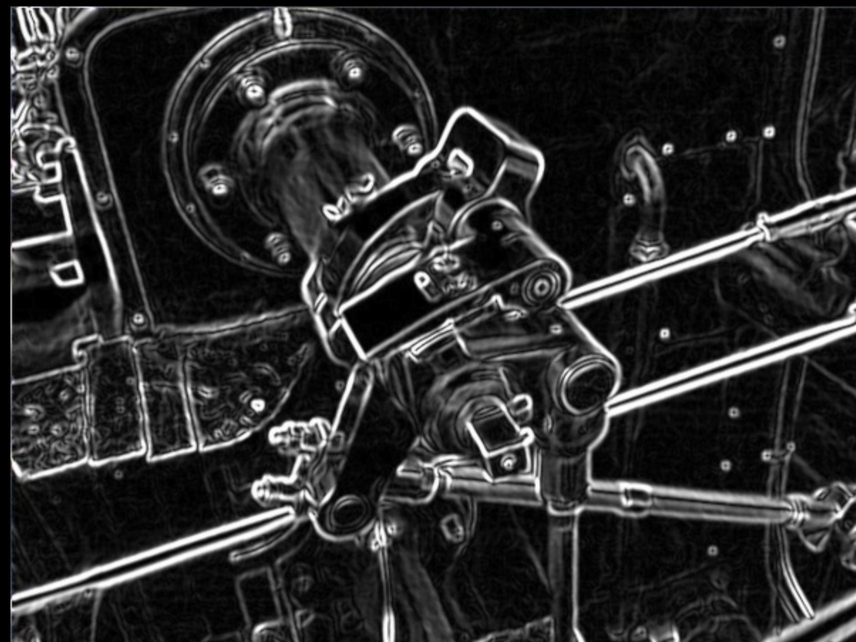
output

high value = edge

Sobel Filter Example



Input



Output

Source: Wikipedia

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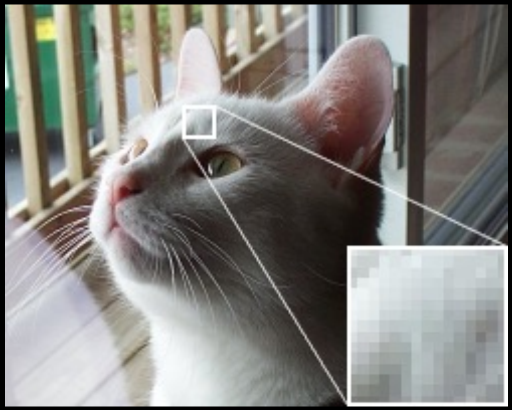
Dithering

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



original

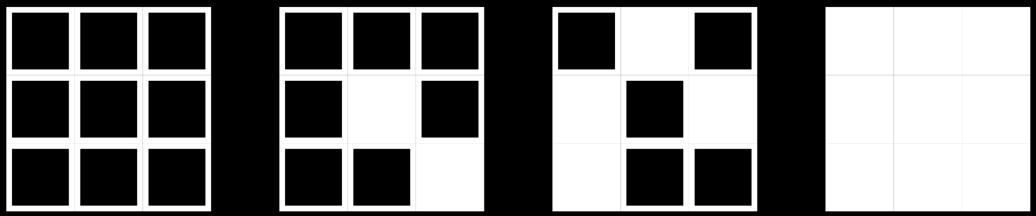
web-safe colors,
no dithering

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

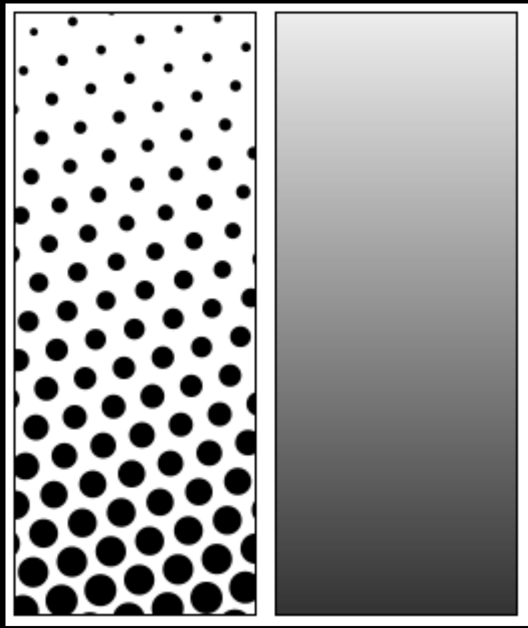
original image, k=8
256 colors per
RGB channel

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