CMPSCI 370: Intro to Computer Vision
Image processing
[linear filtering]

University of Massachusetts, Amherst
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Instructor: Subhransu Maji

Slides credit: L. Lazebnik and others

Enhancing images

- What can we do to “enhance” an image after it has already been digitized?
- We can make the information that is there easier to visualize.
- We can guess at data that is not there, but we cannot be sure, in general.

Contrast stretching

Before

After

histogram

map this to 255

map this to 0

image source: wikipedia

Administrivia

- Homework 2 will be posted today
- Will be due Tue., Feb. 23 before class
- Questions on
  - Linearity of light
  - Color constancy
  - Hybrid images — (today)

- Get started early
Motivation: Image de-noising

• How can we reduce noise in a photograph?

Moving average

• Let’s replace each pixel with a **weighted** average of its neighborhood
• The weights are called the **filter**
• What are the weights for the average of a 3x3 neighborhood?

![Box filter](image)

Convolution

• Let \( f \) be the image and \( g \) be the kernel. The output of convolving \( f \) with \( g \) is denoted \( f \ast g \).

\[
(f \ast g)[m,n] = \sum_{k,l} f[m-k, n-l] g[k, l]
\]

Some properties

• **Linearity:** \( \text{filter}(f_1 + f_2) = \text{filter}(f_1) + \text{filter}(f_2) \)
• ** Scalars factor out:** \( \text{filter}(k \cdot f_1) = k \cdot \text{filter}(f_1) \)

MATLAB functions: `conv2`, `filter2`, `imfilter`
What is the size of the output?

- MATLAB: `filter2(g, f, shape)` or `conv2(g, f, shape)`
  - `shape = 'full'`: output size is sum of sizes of f and g
  - `shape = 'same'`: output size is same as f
  - `shape = 'valid'`: output size is difference of sizes of f and g

What about near the edge?
- the filter window falls off the edge of the image
- need to extrapolate
- methods (MATLAB):
  - clip filter (black): `imfilter(f, g, 0)`
  - wrap around: `imfilter(f, g, 'circular')`
  - copy edge: `imfilter(f, g, 'replicate')`
  - reflect across edge: `imfilter(f, g, 'symmetric')`

Practice with linear filters

Original

Source: D. Lowe
Practice with linear filters

Practice with linear filters

Practice with linear filters

Practice with linear filters

Original

Filtered (no change)

Original

Original

Original

Shifted left By 1 pixel

Original

?
Practice with linear filters

**Blur (with a box filter)**

Original

\[
\begin{array}{ccc}
1 & 1 & 1 \\
1 & 1 & 1 \\
1 & 1 & 1 \\
\end{array}
\]

Original

\[
\begin{array}{ccc}
0 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & 0 \\
\end{array}
\]

(Note that filter sums to 1)

**Sharpening**

Original

\[
\begin{array}{ccc}
0 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & 0 \\
\end{array}
\]

\[
\begin{array}{ccc}
1 & 1 & 1 \\
1 & 1 & 1 \\
1 & 1 & 1 \\
\end{array}
\]

Sharpening filter

- Accentuates differences with local average

**Sharpening**

before

after

Source: D. Lowe
What's wrong with this picture?
What's the solution?

To eliminate edge effects, weight contribution of neighborhood pixels according to their closeness to the center

“fuzzy blob”

Gaussian Kernel

\[ G_\sigma = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}} \]

- Constant factor at front makes volume sum to 1 (can be ignored when computing the filter values, as we should renormalize weights to sum to 1 in any case)

- Standard deviation \( \sigma \): determines extent of smoothing
Choosing kernel width

- The Gaussian function has infinite support, but discrete filters use finite kernels.

Choosing kernel width

- Rule of thumb: set filter half-width to about $3\sigma$

Gaussian vs. box filtering

- Salt and pepper noise: contains random occurrences of black and white pixels
- Impulse noise: contains random occurrences of white pixels
- Gaussian noise: variations in intensity drawn from a Gaussian normal distribution

Matlab command:
```
>> fspecial('gaussian', hsize, sigma)
```

Source: K. Grauman

Noise

Source: S. Seitz
Gaussian noise

- Mathematical model: sum of many independent factors
- Good for small standard deviations
- Assumption: independent, zero-mean noise

\[ f(x,y) = f(x,y) + \text{Noise process } \mathcal{N}(x) \]

Source: M. Hebert

Reducing Gaussian noise

Smoothing with larger standard deviations suppresses noise, but also blurs the image

Reducing salt-and-pepper noise

3x3 5x5 7x7

What’s wrong with the results?

A median filter operates over a window by selecting the median intensity in the window

- Is median filtering linear?

Source: K. Grauman
Median filter

- What advantage does median filtering have over Gaussian filtering?
- Robustness to outliers

Let's add it back:

Sharpening revisited

What does blurring take away?

Let's add it back:

Sharpening filter

\[ I = \text{blurry}(I) + \text{sharp}(I) \]

\[ \text{sharp}(I) = I - \text{blurry}(I) \]

\[ = I * e - I * g_\sigma \]

\[ = I * (e - g_\sigma) \]
Application: Hybrid Images

- Gaussian Filter
- Laplacian Filter


Changing expression

Sad → Surprised

motorcycle and bicycle

dolphin and car

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