Lecture 1: Images and image filtering

Hybrid Images, Oliva et al., http://olivalab.mit.edu/hybridimage.htm
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CS5670: Intro to Computer Vision
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Lecture 1: Images and image filtering

Hybrid Images, Oliva et al., http://olivalab.mit.edu/hybridimage.htm
Reading

• Szeliski, Chapter 3.1-3.3
Announcements

- Project 1 (Hybrid Images) will be released early next week
  - Code due Friday, Feb 10
  - This project will be done solo
  - Other projects planned to be done in groups of 2

- Project is in Python – we will provide skeleton code and instructions for setting up a Python environment for the project
What is an image?
What is an image?

We’ll focus on these in this class

(More on this process later)
What is an image?

- A grid (matrix) of intensity values

(common to use one byte per value: 0 = black, 255 = white)
What is an image?

- Can think of a (grayscale) image as a **function** $f$ from $\mathbb{R}^2$ to $\mathbb{R}$:
  - $f(x,y)$ gives the **intensity** at position $(x,y)$

- A **digital** image is a discrete (**sampled, quantized**) version of this function
Image transformations

• As with any function, we can apply operators to an image

\[ g(x,y) = f(x,y) + 20 \]

\[ g(x,y) = f(-x,y) \]

• Today we’ll talk about a special kind of operator, convolution (linear filtering)
Filters

• Filtering
  – Form a new image whose pixel values are a combination of the original pixel values

• Why?
  – To get useful information from images
    • E.g., extract edges or contours (to understand shape)
  – To enhance the image
    • E.g., to remove noise
    • E.g., to sharpen and “enhance image” a la CSI
  – A key operator in Convolutional Neural Networks
Canonical Image Processing problems

• Image Restoration
  – denoising
  – deblurring
• Image Compression
  – JPEG, HEIF, MPEG, ...
• Locating Structural Features
  – corners
  – edges
Question: Noise reduction

• Given a camera and a still scene, how can you reduce noise?

Take lots of images and average them!

What’s the next best thing?

Source: S. Seitz
Image filtering

• Modify the pixels in an image based on some function of a local neighborhood of each pixel

\[
\begin{array}{ccc}
10 & 5 & 3 \\
4 & 5 & 1 \\
1 & 1 & 7 \\
\end{array}
\]

Local image data

Some function

\[
\begin{array}{ccc}
\quad & \\
\quad & 7 \\
\quad & \\
\end{array}
\]

Modified image data

Source: L. Zhang
Linear filtering

- One simple version of filtering: linear filtering (cross-correlation, convolution)
  - Replace each pixel by a linear combination (a weighted sum) of its neighbors
- The prescription for the linear combination is called the “kernel” (or “mask”, “filter”)

![Local image data](source: L. Zhang) -> ![kernel](source: L. Zhang) -> ![Modified image data](source: L. Zhang)
**Cross-correlation**

Let \( F \) be the image, \( H \) be the kernel (of size \( 2k+1 \times 2k+1 \)), and \( G \) be the output image.

\[
G[i, j] = \sum_{u=-k}^{k} \sum_{v=-k}^{k} H[u, v] F[i + u, j + v]
\]

This is called a **cross-correlation** operation:

\[
G = H \otimes F
\]

- Can think of as a “dot product” between local neighborhood and kernel for each pixel
Convolution

- Same as cross-correlation, except that the kernel is “flipped” (horizontally and vertically)

\[ G[i, j] = \sum_{u=-k}^{k} \sum_{v=-k}^{k} H[u, v] F[i - u, j - v] \]

This is called a convolution operation:

\[ G = H \ast F \]

- Convolution is commutative and associative
Convolution

Adapted from F. Durand
Mean filtering

\[ H \ast F = G \]
Mean filtering/Moving average

\[ F[x, y] \]

\[ G[x, y] \]
Mean filtering/Moving average

<table>
<thead>
<tr>
<th>$F[x, y]$</th>
<th>$G[x, y]$</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Matrix F" /></td>
<td><img src="image" alt="Matrix G" /></td>
</tr>
</tbody>
</table>
Mean filtering/Moving average

\[ F[x, y] \]

\[ G[x, y] \]
Mean filtering/Moving average

\[ F[x, y] \]

\[ G[x, y] \]
Mean filtering/Moving average

\[ F[x, y] \]

\[ G[x, y] \]
Mean filtering/Moving average

\[ F[x, y] \]

\[ G[x, y] \]
Linear filters: examples

Source: D. Lowe
What image operation does filtering with this kernel perform?
([0 0 0; 0 1 0; 0 0 0])
Linear filters: examples

Original \* \[
\begin{array}{ccc}
0 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 0 \\
\end{array}
\] = Identical image

Source: D. Lowe
Linear filters: examples

Original

Source: D. Lowe
What image operation does filtering with this kernel perform? ([0 0 0; 1 0 0; 0 0 0])
Linear filters: examples

Original \* \begin{array}{ccc} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{array} = \text{Shifted left by 1 pixel}

Source: D. Lowe
Linear filters: examples

Original

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

\[ \frac{1}{9} \]

\[ = \]

Blur (with a mean filter)

Source: D. Lowe
Linear filters: examples

Original

\[
\begin{pmatrix}
0 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & 0 \\
\end{pmatrix}
\] - \[\frac{1}{9}\]

\[
\begin{pmatrix}
1 & 1 & 1 \\
1 & 1 & 1 \\
1 & 1 & 1 \\
\end{pmatrix}
\] =

Sharpening filter
(accentuates edges)

Source: D. Lowe
Sharpening

before

after

Source: D. Lowe
Smoothing with box filter revisited

Source: D. Forsyth
Gaussian kernel

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

Source: C. Rasmussen
Gaussian filters

$\sigma = 1$ pixel
$\sigma = 5$ pixels
$\sigma = 10$ pixels
$\sigma = 30$ pixels
Mean vs. Gaussian filtering
Gaussian filter

- Removes “high-frequency” components from the image (low-pass filter)
- Convolution with self is another Gaussian

\[ \ast \]

- Convolving twice with Gaussian kernel of width \( \sigma \)
  \[ = \text{convolving once with kernel of } \sqrt{2} \sigma \]
Sharpening revisited

• What does blurring take away?

Let's add it back:

(This “detail extraction” operation is also called a high-pass filter)

Photo credit: https://www.flickr.com/photos/qeezaweezer/16089096376/
Sharpen filter

\[ F + \alpha (F - F \ast H) = \]

- scaled impulse
- blurred image
- unit impulse (identity kernel with single 1 in center, zeros elsewhere)

Gaussian
Sharpen filter

unfiltered

filtered
“Optical” convolution

Camera shake

= *


**Bokeh**: Blur in out-of-focus regions of an image.

Source: [https://www.diyphtography.net/diy_create_your_own_bokeh/](https://www.diyphtography.net/diy_create_your_own_bokeh/)
Filters: Thresholding

\[ g(m, n) = \begin{cases} 
255, & f(m, n) > A \\
0, & \text{otherwise} 
\end{cases} \]
Linear filters

• Can thresholding be implemented with a linear filter?
Can thresholding be implemented with a linear filter?
Questions?