Lecture 1: Images and image filtering

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

• Szeliski, Chapter 3.1-3.2
What is an image?

We’ll focus on these in this class

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

• A grid of intensity values

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

- We 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

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

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

• We’ll talk about a special kind of operator, *convolution* (linear filtering)
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

Source: L. Zhang
Linear filtering

• One simple version: linear filtering (cross-correlation, convolution)
  – Replace each pixel by a linear combination of its neighbors

• The prescription for the linear combination is called the “kernel” (or “mask”, “filter”)

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<tbody>
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</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>8</th>
</tr>
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</table>
```

Local image data  kernel  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 \textbf{cross-correlation} operation:

$$G = H \otimes F$$
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 / cross-correlation are commutative and associative
Convolution

Adapted from F. Durand
Mean filtering

\[ H \ast F = G \]
Linear filters: examples

Original * [0 0 0; 0 1 0; 0 0 0] = Identical image

Source: D. Lowe
Linear filters: examples

Original

\[
\begin{bmatrix}
0 & 0 & 0 \\
1 & 0 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\]

Shifted left by 1 pixel

Source: D. Lowe
Linear filters: examples

Source: D. Lowe
Linear filters: examples

Original

\[
\begin{pmatrix}
0 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & 0 \\
\end{pmatrix}
\ast \left( \begin{pmatrix}
1 & 1 & 1 \\
1 & 1 & 1 \\
1 & 1 & 1 \\
\end{pmatrix} - \frac{1}{9} \right) =
\]

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
Mean vs. Gaussian filtering
Gaussian filter

• Removes “high-frequency” components from the image (low-pass filter)

• Convolution with self is another Gaussian

\[ \ast \]

– Convolving two times with Gaussian kernel of width \( \sigma = \) convolving once with kernel of width \( \sigma \sqrt{2} \)

Source: K. Grauman
Sharpening revisited

• What does blurring take away?

\[
\text{original} - \text{smoothed (5x5)} = \text{detail}
\]

Let’s add it back:

\[
\text{original} + \alpha \text{detail} = \text{sharpened}
\]

Source: S. Lazebnik
Sharpen filter

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

Image

Blurred image

Scaled impulse

Gaussian

Laplacian of Gaussian

Unit impulse (identity)
Sharpen filter

unfiltered

filtered
Convolution in the real world

Camera shake

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

Source: http://lullaby.homepage.dk/diy-camera/bokeh.html
Questions?

• For next time:
  – Read Szeliski, Chapters 1, 3.1-3.2

• Next time:
  – See you on Tuesday, Sept. 8!
  – Feature and edge detection