Lecture 1: Introduction to computer vision and simple edge detection

Dr. Richard E. Turner (ret26@cam.ac.uk)

April 29, 2014
House keeping

• computer vision section website [http://cbl.eng.cam.ac.uk/Public/Turner/Teaching](http://cbl.eng.cam.ac.uk/Public/Turner/Teaching)
  – all materials posted here

• there will be one example sheet
Gaussian quiz \( g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp \left(-\frac{x^2}{2\sigma^2}\right) \)

1) Derivative of a Gaussian
\[ \frac{d}{dx} g_\sigma(x) \]

2) Second derivative of a Gaussian
\[ \frac{d^2}{dx^2} g_\sigma(x) \]

3) Multiplication of two Gaussians
\[ g_{\sigma_1}(x) g_{\sigma_2}(x) \]

4) Fourier Transform of a Gaussian
\[ \int \exp(ikx) g_\sigma(x) dx \]

5) Convolution of 2 Gaussians
\[ \int g_{\sigma_1}(x - x') g_{\sigma_2}(x') dx \]

6) Fourier Transform derivative of Gaussian
\[ \text{FT} \left( \frac{d}{dx} g_\sigma(x) \right) \]
Gaussian quiz $g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right)$

1) Derivative of a Gaussian $= b$

$$\frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x)$$

2) Second derivative of a Gaussian

$$\frac{d^2}{dx^2} g_\sigma(x)$$

3) Multiplication of two Gaussians

$$g_{\sigma_1}(x) g_{\sigma_2}(x)$$

4) Fourier Transform of a Gaussian

$$\int \exp(i k x) g_\sigma(x) dx$$

5) Convolution of 2 Gaussians

$$\int g_{\sigma_1}(x - x') g_{\sigma_2}(x') dx$$

6) Fourier Transform derivative of Gaussian

$$\text{FT} \left( \frac{d}{dx} g_\sigma(x) \right)$$
Gaussian quiz \[ g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \]

1) Derivative of a Gaussian \[ \frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x) \]

2) Second derivative of a Gaussian \[ \frac{d^2}{dx^2} g_\sigma(x) \]

3) Multiplication of two Gaussians \[ g_{\sigma_1}(x) g_{\sigma_2}(x) \]

4) Fourier Transform of a Gaussian \[ \int \exp(i k x) g_\sigma(x) dx \]

5) Convolution of 2 Gaussians \[ \int g_{\sigma_1}(x-x') g_{\sigma_2}(x') dx' \]

6) Fourier Transform derivative of Gaussian \[ \text{FT} \left( \frac{d}{dx} g_\sigma(x) \right) \]
Gaussian quiz \[ g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \]

1) Derivative of a Gaussian \( = b \)
\[
\frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x)
\]

2) Second derivative of a Gaussian \( = d \)
\[
\frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left(\frac{x^2}{\sigma^2} - 1\right) g_\sigma(x)
\]

3) Multiplication of two Gaussians
\[ g_{\sigma_1}(x) g_{\sigma_2}(x) \]

4) Fourier Transform of a Gaussian
\[
\int \exp(ikx) g_\sigma(x) \text{d}x
\]

5) Convolution of 2 Gaussians
\[
\int g_{\sigma_1}(x - x') g_{\sigma_2}(x') \text{d}x
\]

6) Fourier Transform derivative of Gaussian
\[
\text{FT} \left( \frac{d}{dx} g_\sigma(x) \right)
\]
Gaussian quiz \( g_{\sigma}(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp(-\frac{x^2}{2\sigma^2}) \)

1) Derivative of a Gaussian \( = b \)
\[
\frac{d}{dx} g_{\sigma}(x) = -\frac{x}{\sigma^2} g_{\sigma}(x)
\]

2) Second derivative of a Gaussian \( = d \)
\[
\frac{d^2}{dx^2} g_{\sigma}(x) = \frac{1}{\sigma^2} \left(\frac{x^2}{\sigma^2} - 1\right) g_{\sigma}(x)
\]

3) Multiplication of two Gaussians
\[
g_{\sigma_1}(x)g_{\sigma_2}(x)
\]

4) Fourier Transform of a Gaussian
\[
\int \exp(ikx) g_{\sigma}(x) \, dx
\]

5) Convolution of 2 Gaussians
\[
\int g_{\sigma_1}(x - x')g_{\sigma_2}(x') \, dx
\]

6) Fourier Transform derivative of Gaussian
\[
\text{FT} \left( \frac{d}{dx} g_{\sigma}(x) \right)
\]
Gaussian quiz \( g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \)

1) Derivative of a Gaussian \( = b \)
\[
\frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x)
\]

2) Second derivative of a Gaussian \( = d \)
\[
\frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left( \frac{x^2}{\sigma^2} - 1 \right) g_\sigma(x)
\]

3) Multiplication of two Gaussians \( = a \)
\[
g_{\sigma_1}(x)g_{\sigma_2}(x) = g_{\sigma_3}(x)
\]

4) Fourier Transform of a Gaussian
\[
\int \exp(ikx)g_\sigma(x)dx
\]

5) Convolution of 2 Gaussians
\[
\int g_{\sigma_1}(x-x')g_{\sigma_2}(x')dx
\]

6) Fourier Transform derivative of Gaussian
\[
\text{FT} \left( \frac{d}{dx} g_\sigma(x) \right)
\]
Gaussian quiz  \[ g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \]

1) Derivative of a Gaussian  = b
\[ \frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x) \]

2) Second derivative of a Gaussian  = d
\[ \frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left( \frac{x^2}{\sigma^2} - 1 \right) g_\sigma(x) \]

3) Multiplication of two Gaussians  = a
\[ g_{\sigma_1}(x)g_{\sigma_2}(x) = g_{\sigma_3}(x) \quad \sigma_3^{-2} = \sigma_1^{-2} + \sigma_2^{-2} \]

4) Fourier Transform of a Gaussian
\[ \int \exp(i k x) g_\sigma(x) \, dx \]

5) Convolution of 2 Gaussians
\[ \int g_{\sigma_1}(x-x')g_{\sigma_2}(x') \, dx \]

6) Fourier Transform derivative of Gaussian
\[ \text{FT} \left( \frac{d}{dx} g_\sigma(x) \right) \]
Gaussian quiz \[ g_\sigma(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \]

1) Derivative of a Gaussian \( = b \)
\[ \frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x) \]

2) Second derivative of a Gaussian \( = d \)
\[ \frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left(\frac{x^2}{\sigma^2} - 1\right) g_\sigma(x) \]

3) Multiplication of two Gaussians \( = a \)
\[ g_{\sigma_1}(x) g_{\sigma_2}(x) = g_{\sigma_3}(x) \quad \sigma_3^{-2} = \sigma_1^{-2} + \sigma_2^{-2} \]

4) Fourier Transform of a Gaussian \( = a \)
\[ \int \exp(ikx) g_\sigma(x) dx \propto g_{\sigma'}(k) \]

5) Convolution of 2 Gaussians
\[ \int g_{\sigma_1}(x - x') g_{\sigma_2}(x') dx \]

6) Fourier Transform derivative of Gaussian
\[ \text{FT} \left( \frac{d}{dx} g_\sigma(x) \right) \]
Gaussian quiz \( g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \)

1) Derivative of a Gaussian \( = b \)
\[
\frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x)
\]

2) Second derivative of a Gaussian \( = d \)
\[
\frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left(\frac{x^2}{\sigma^2} - 1\right) g_\sigma(x)
\]

3) Multiplication of two Gaussians \( = a \)
\[
g_{\sigma_1}(x)g_{\sigma_2}(x) = g_{\sigma_3}(x) \quad \sigma_3^{-2} = \sigma_1^{-2} + \sigma_2^{-2}
\]

4) Fourier Transform of a Gaussian \( = a \)
\[
\int \exp(ikx)g_\sigma(x)dx \propto g_{\sigma'}(k) \quad \sigma' = \frac{1}{\sigma}
\]

5) Convolution of 2 Gaussians
\[
\int g_{\sigma_1}(x-x')g_{\sigma_2}(x')dx
\]

6) Fourier Transform derivative of Gaussian
\[
\text{FT} \left( \frac{d}{dx} g_\sigma(x) \right)
\]
Gaussian quiz  \[ g_\sigma(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \]

1) Derivative of a Gaussian  = b
\[
\frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x)
\]

2) Second derivative of a Gaussian  = d
\[
\frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left(\frac{x^2}{\sigma^2} - 1\right) g_\sigma(x)
\]

3) Multiplication of two Gaussians  = a
\[
g_{\sigma_1}(x) g_{\sigma_2}(x) = g_{\sigma_3}(x) \quad \sigma_3^{-2} = \sigma_1^{-2} + \sigma_2^{-2}
\]

4) Fourier Transform of a Gaussian  = a
\[
\int \exp(ikx) g_\sigma(x) dx \propto g_{\sigma'}(k) \quad \sigma' = \frac{1}{\sigma}
\]

5) Convolution of 2 Gaussians  = a
\[
\int g_{\sigma_1}(x-x') g_{\sigma_2}(x') dx = g_{\sigma_3}(x)
\]

6) Fourier Transform derivative of Gaussian
\[
\text{FT} \left( \frac{d}{dx} g_\sigma(x) \right)
\]
Gaussian quiz \[ g_\sigma(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \]

1) Derivative of a Gaussian = b
\[ \frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x) \]

2) Second derivative of a Gaussian = d
\[ \frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left( \frac{x^2}{\sigma^2} - 1 \right) g_\sigma(x) \]

3) Multiplication of two Gaussians = a
\[ g_{\sigma_1}(x) g_{\sigma_2}(x) = g_{\sigma_3}(x) \quad \sigma_3^{-2} = \sigma_1^{-2} + \sigma_2^{-2} \]

4) Fourier Transform of a Gaussian = a
\[ \int \exp(i k x) g_\sigma(x) \, dx \propto g_{\sigma'}(k) \quad \sigma' = \frac{1}{\sigma} \]

5) Convolution of 2 Gaussians = a
\[ \int g_{\sigma_1}(x - x') g_{\sigma_2}(x') \, dx = g_{\sigma_3}(x) \]
\[ \sigma_3^2 = \sigma_1^2 + \sigma_2^2 \]

6) Fourier Transform derivative of Gaussian
\[ \text{FT} \left( \frac{d}{dx} g_\sigma(x) \right) \]
Gaussian quiz  \[ g_\sigma(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \]

1) Derivative of a Gaussian  = b
\[ \frac{d}{dx} g_\sigma(x) = -\frac{x}{\sigma^2} g_\sigma(x) \]

2) Second derivative of a Gaussian  = d
\[ \frac{d^2}{dx^2} g_\sigma(x) = \frac{1}{\sigma^2} \left(\frac{x^2}{\sigma^2} - 1\right) g_\sigma(x) \]

3) Multiplication of two Gaussians  = a
\[ g_{\sigma_1}(x) g_{\sigma_2}(x) = g_{\sigma_3}(x) \quad \sigma_3^{-2} = \sigma_1^{-2} + \sigma_2^{-2} \]

4) Fourier Transform of a Gaussian  = a
\[ \int \exp(ikx) g_\sigma(x) \, dx \propto g_{\sigma'}(k) \quad \sigma' = \frac{1}{\sigma} \]

5) Convolution of 2 Gaussians  = a
\[ \int g_{\sigma_1}(x-x') g_{\sigma_2}(x') \, dx = g_{\sigma_3}(x) \]
\[ \sigma_3^2 = \sigma_1^2 + \sigma_2^2 \]

6) Fourier Transform derivative of Gaussian  = c
\[ \text{FT} \left( \frac{d}{dx} g_\sigma(x) \right) = \text{FT} \left( \frac{d}{dx} \right) \text{FT} \left( g_\sigma(x) \right) \]
Primary Visual Cortex

Neurons in primary visual cortex are driven most strongly by oriented stimuli.

Electrophysiological recordings made in cats show that neurons are tuned for orientation.

Hubel and Wiesel
Nobel Prize in Physiology or Medicine 1981

Neuron (cat) neuron (monkey)

A

stimulus orientation

presentation time

spike train

B

optic nerve lateral geniculate nucleus primary visual cortex

Hubel Wiesel

Nobel Prize in Physiology or Medicine 1981
Primary Visual Cortex

Jones and Palmer 1987, The Two-Dimensional Spatial Structure of Simple Receptive Fields in Cat Striate Cortex