Introduction

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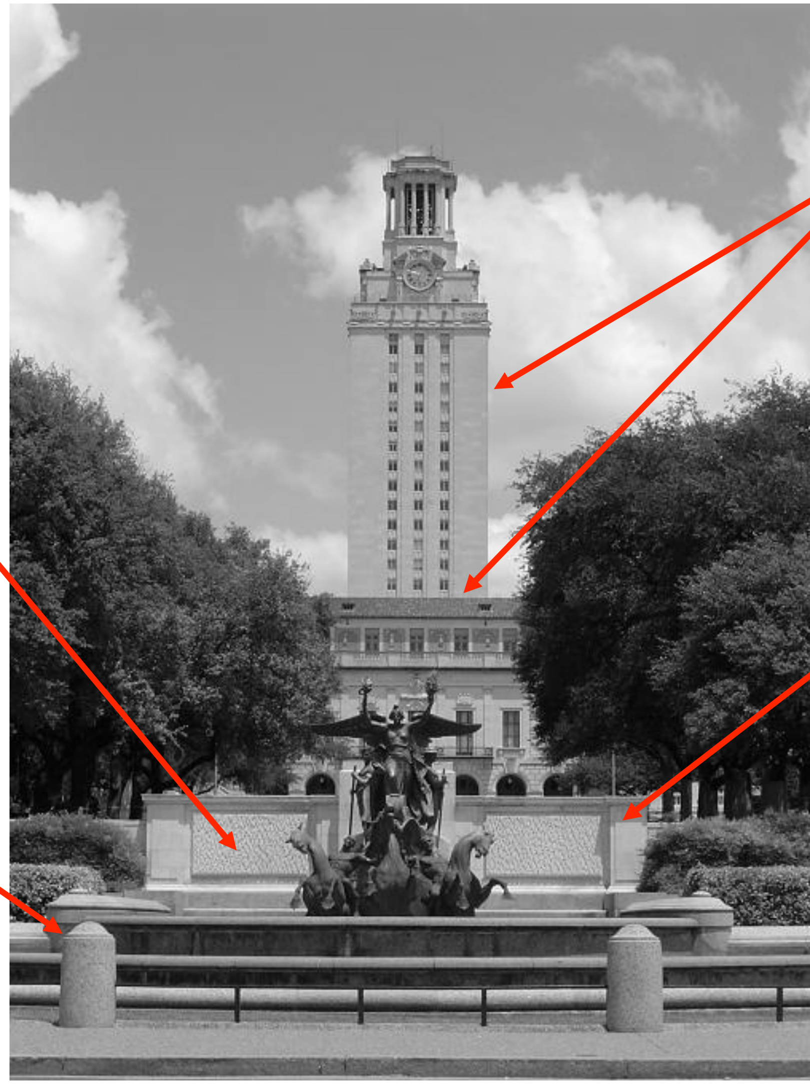
BIL717, February 2012

What causes an edge?



Reflectance change: appearance information, texture

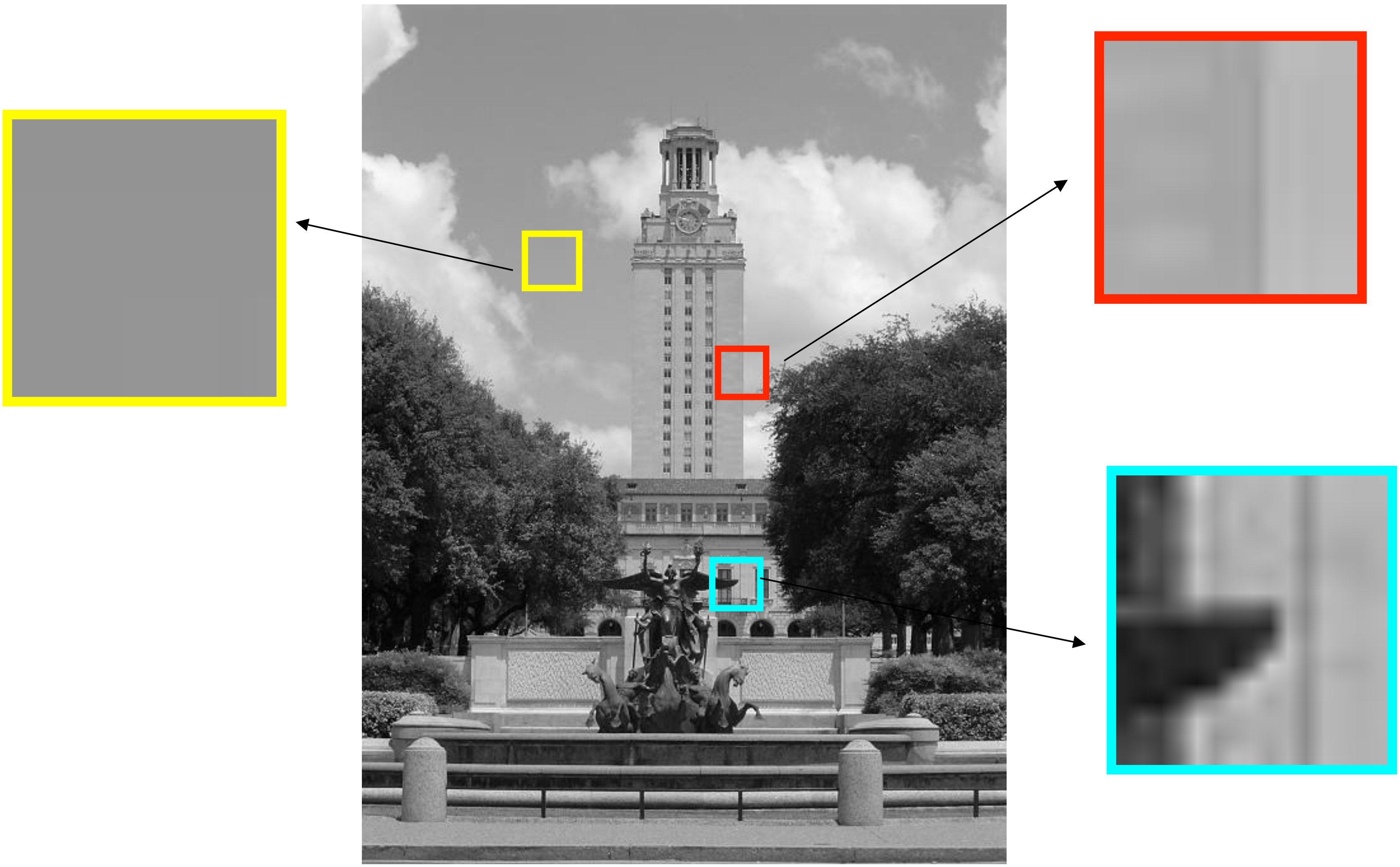
Depth discontinuity: object boundary

Cast shadows

Change in surface orientation: shape

Source: K. Grauman

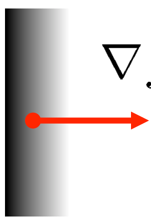
Edges/gradients and invariance



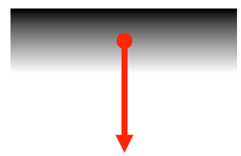
Source: K. Grauman

Image Gradient

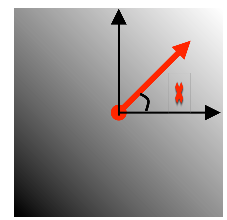
$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$



$$\nabla f = \left[\frac{\partial f}{\partial x}, 0\right]$$



$$\nabla f = \left[0, \frac{\partial f}{\partial y}\right]$$



$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

The gradient direction (orientation of edge normal) is given by:

$$\theta = \tan^{-1}\left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x}\right)$$

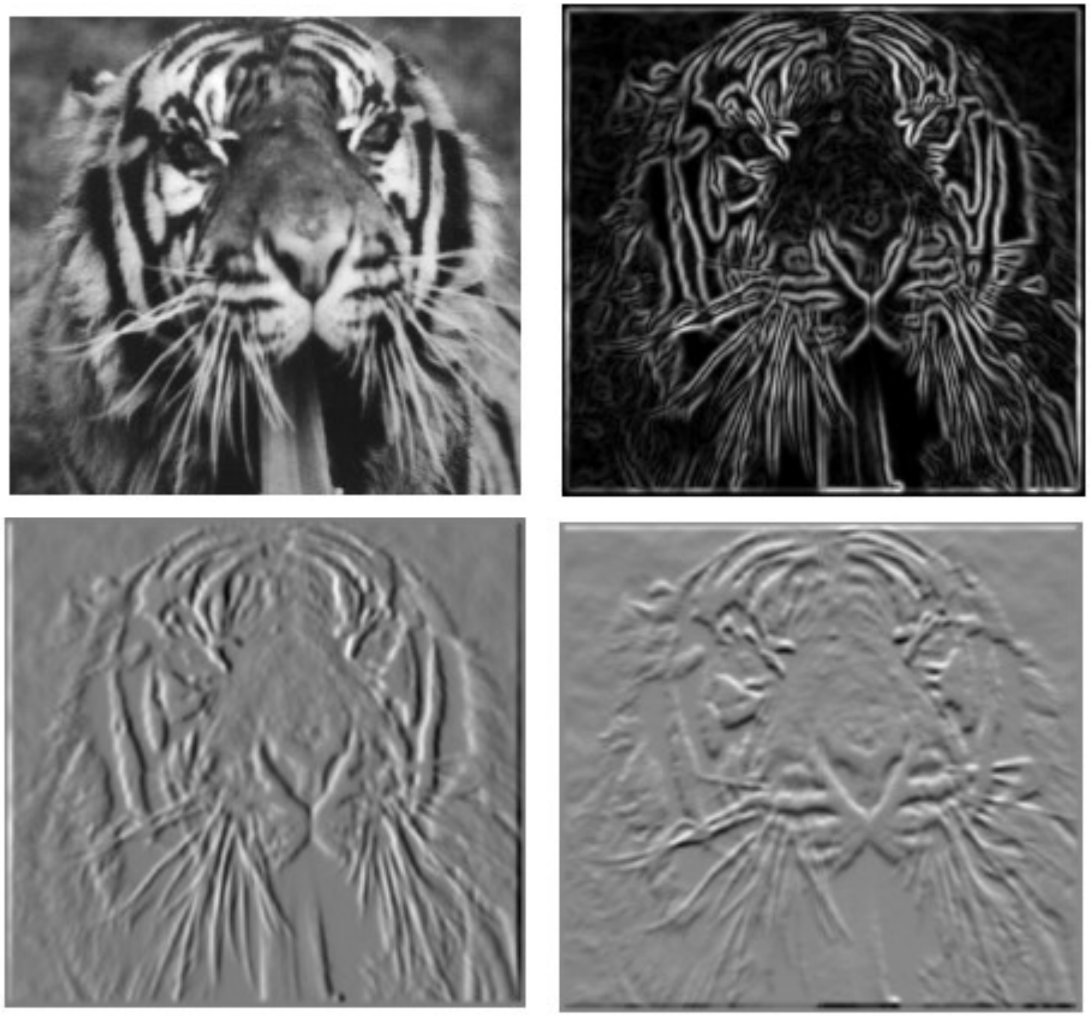
The *edge strength* is given by the gradient magnitude

$$||\nabla f|| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

Source: S. Seitz

Partial derivatives of an image

$$\frac{\partial f(x,y)}{\partial x}$$



$$\frac{\partial f(x,y)}{\partial y}$$

-1	1

-1
1

Source: K. Grauman

Original Image

Source: K. Grauman

Gradient magnitude image

Source: K. Grauman

Thresholding gradient with a lower threshold

Source: K. Grauman

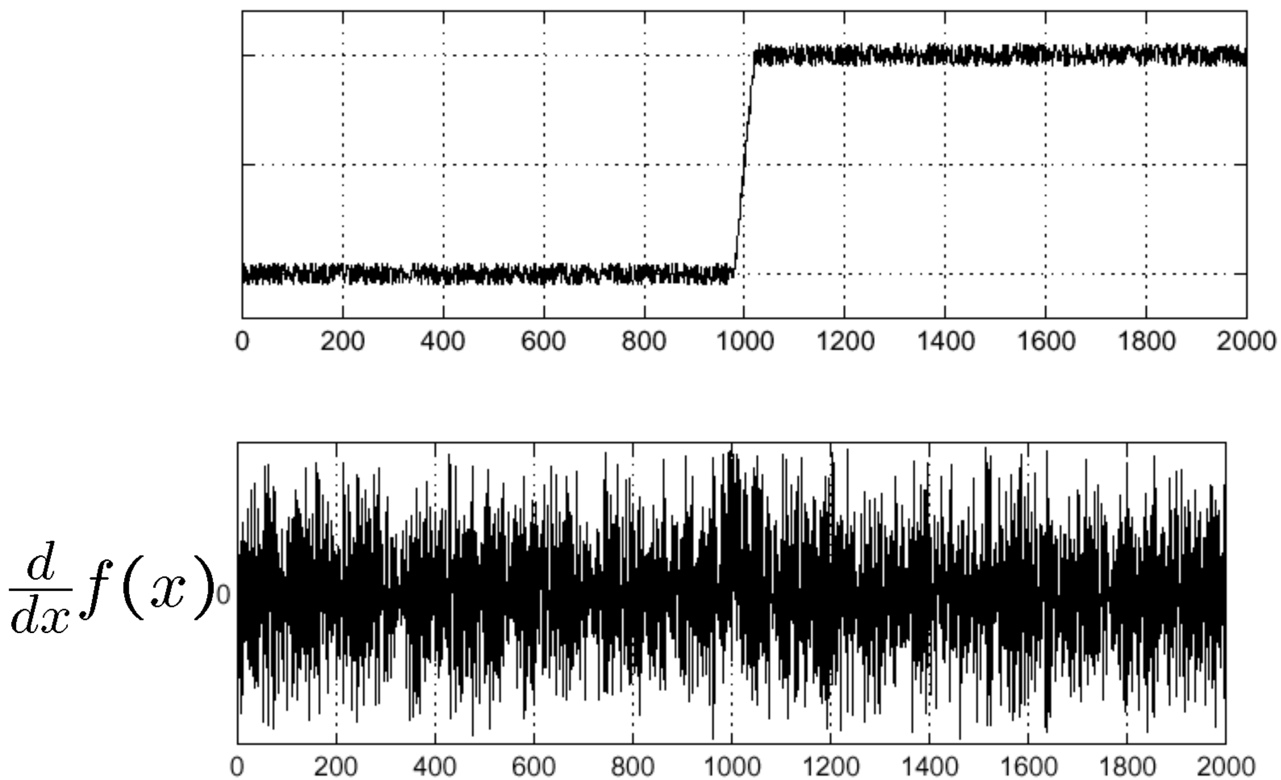
Thresholding gradient with a higher threshold

Source: K. Grauman

Effects of noise

Consider a single row or column of the image

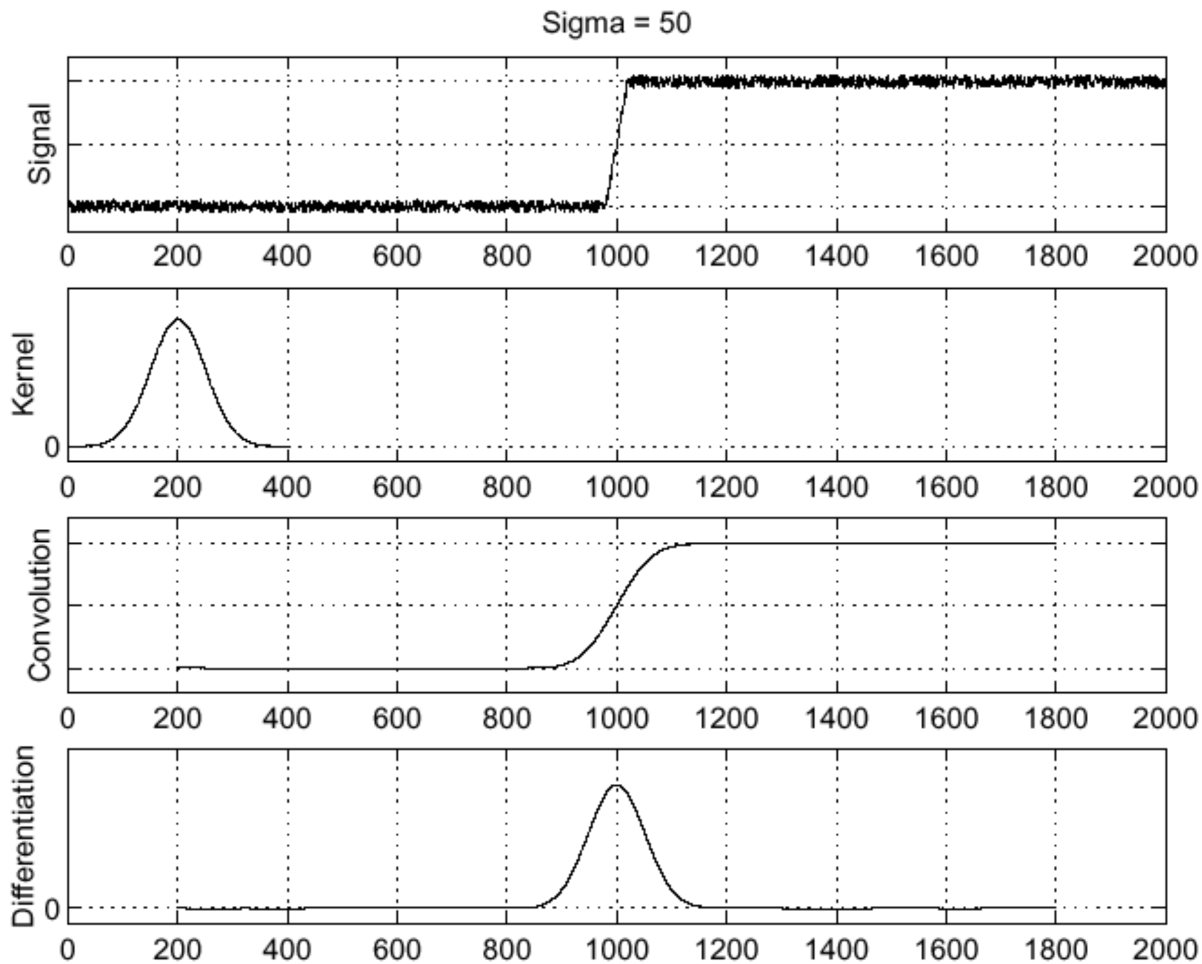
– Plotting intensity as a function of position gives a signal



Where is the edge?

Source: K. Grauman

Solution: Smooth first



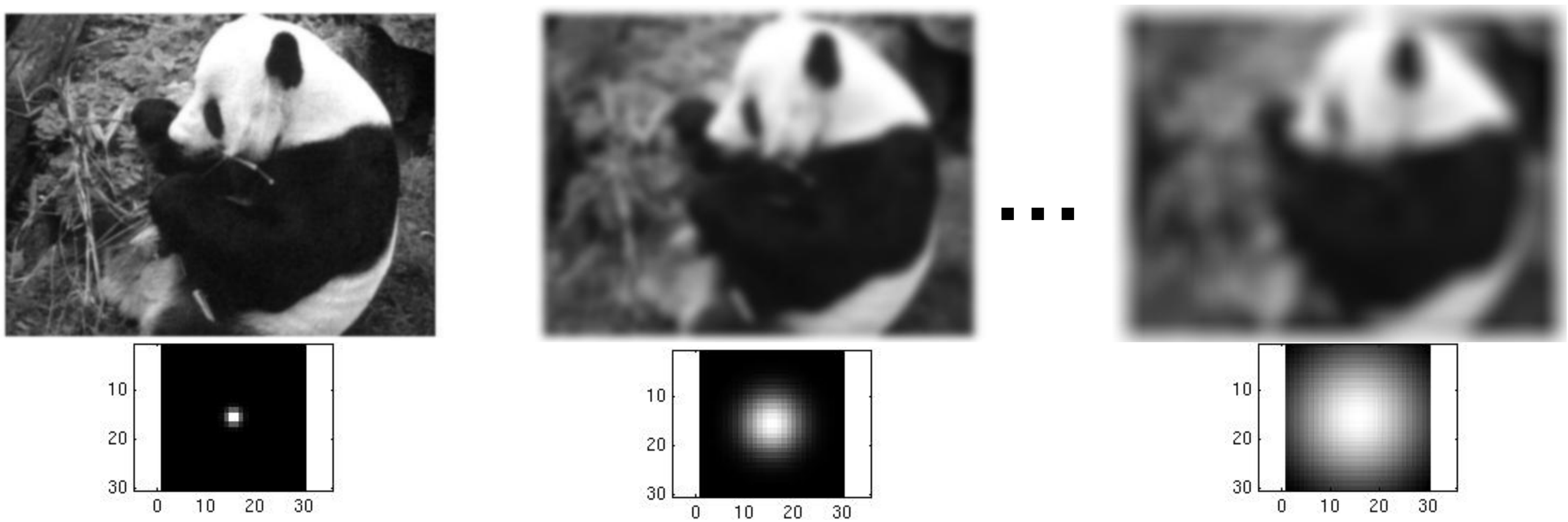
$$\frac{\partial}{\partial x}(h \star f)$$

Where is the edge? Look for peaks in $\frac{\partial}{\partial x}(h \star f)$

Source: K. Grauman

Smoothing with a Gaussian

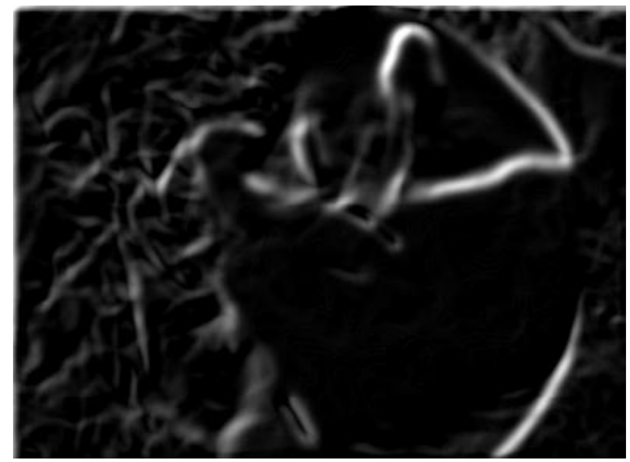
Recall: parameter σ is the "scale" / "width" / "spread" of the Gaussian kernel, and controls the amount of smoothing.



Source: K. Grauman

Effect of σ on derivatives

σ = 1 pixel



σ = 3 pixels

The apparent structures differ depending on Gaussian's scale parameter.

Larger values: larger scale edges detected
Smaller values: finer features detected

Source: K. Grauman

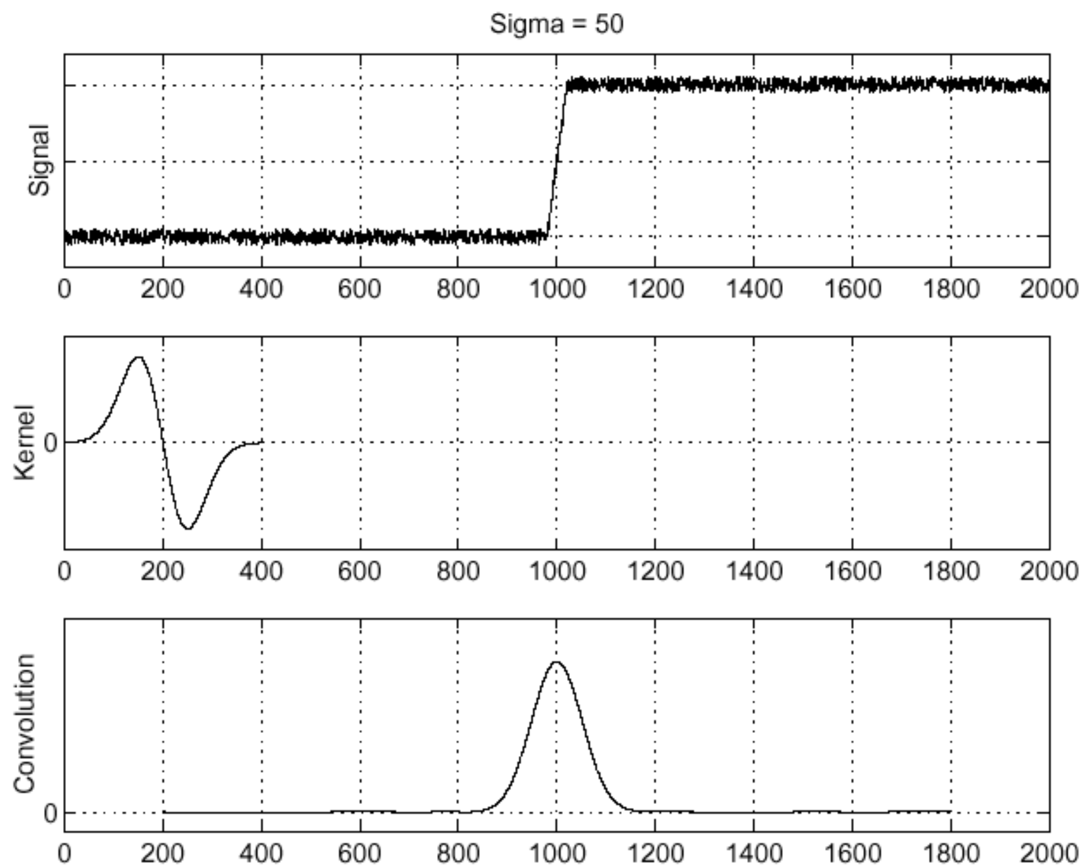
Derivative theorem of convolution

$$\frac{\partial}{\partial x}(h \star f) = (\frac{\partial}{\partial x}h) \star f$$

Differentiation property of convolution.

$$\frac{\partial}{\partial x}h$$

$$(\frac{\partial}{\partial x}h) \star f$$



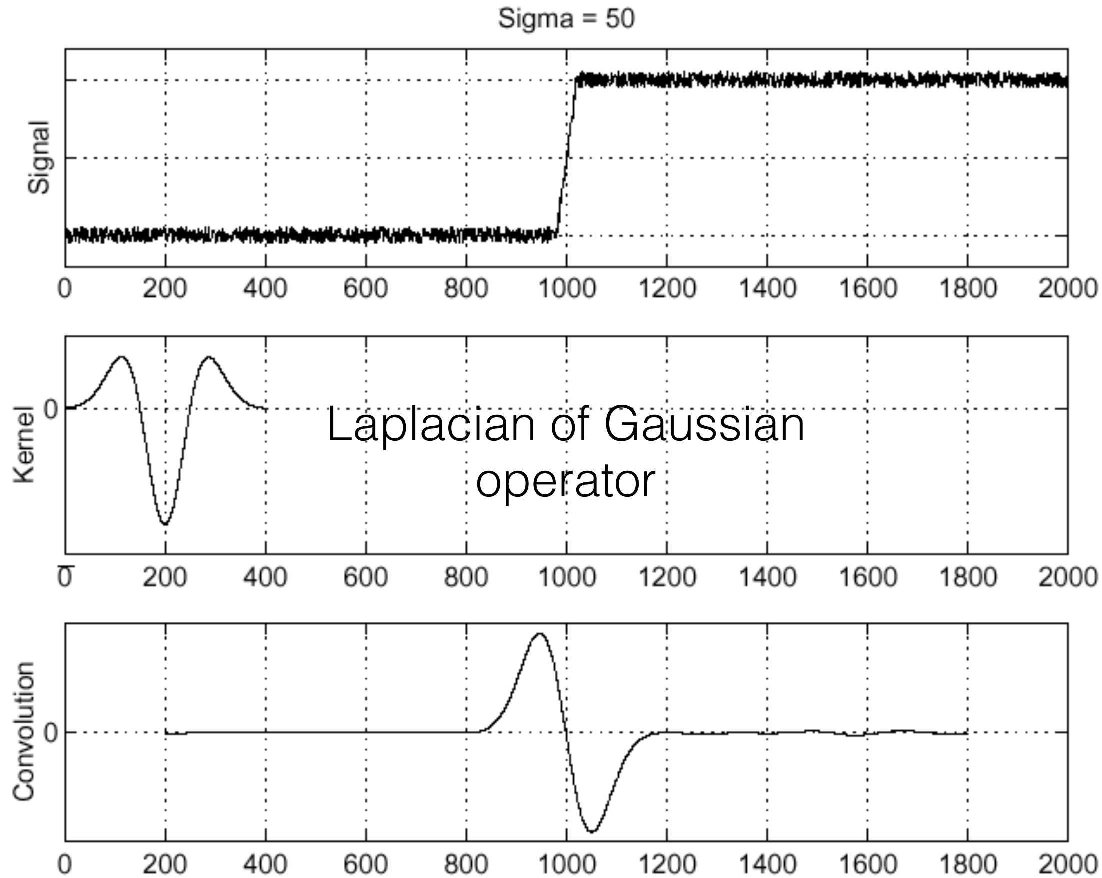
Source: K. Grauman

Laplacian of Gaussian

Consider $\frac{\partial^2}{\partial x^2}(h \star f)$

$$\frac{\partial^2}{\partial x^2}h$$

$$(\frac{\partial^2}{\partial x^2}h) \star f$$

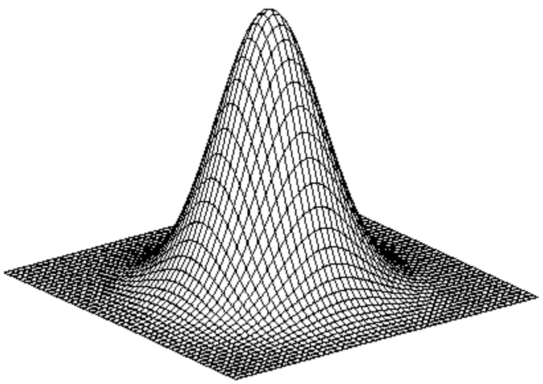


Where is the edge?

Zero-crossings of bottom graph

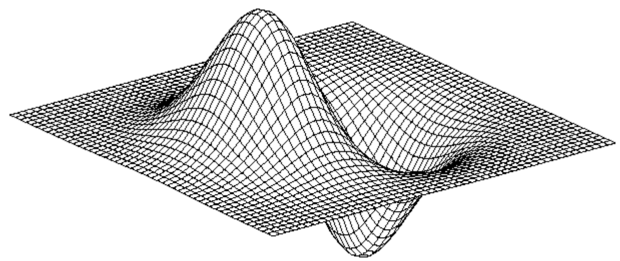
Source: K. Grauman

2D edge detection filters



Gaussian

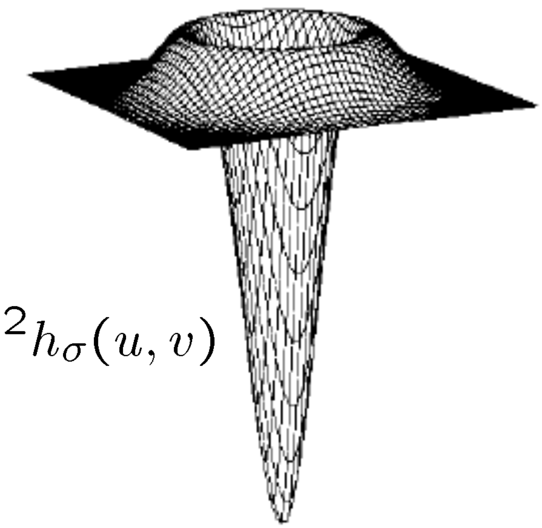
$$h_\sigma(u,v) = \frac{1}{2\pi\sigma^2} e^{-\frac{u^2+v^2}{2\sigma^2}}$$



derivative of Gaussian

$$\frac{\partial}{\partial x} h_\sigma(u,v)$$

Laplacian of Gaussian



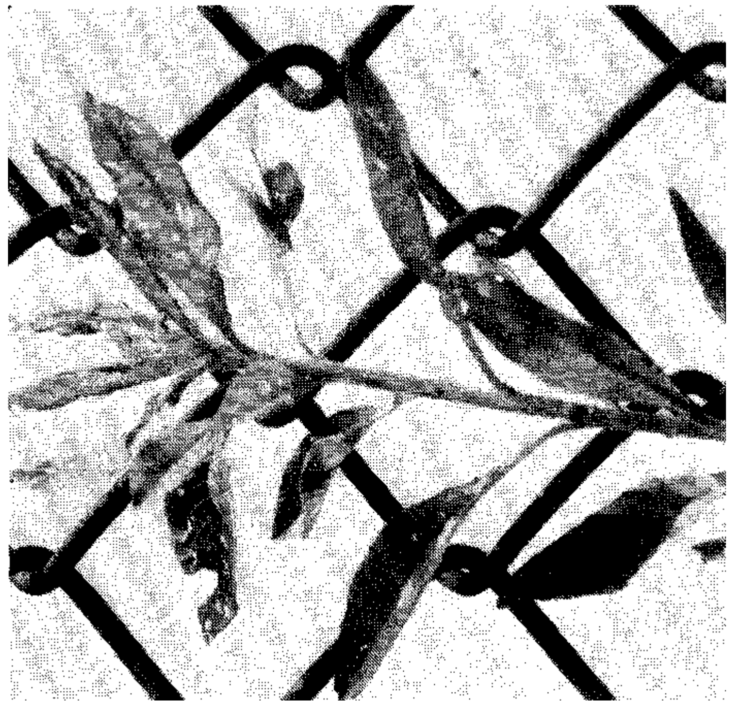
$$\nabla^2 h_\sigma(u,v)$$

- The Laplacian operator:

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

Source: K. Grauman

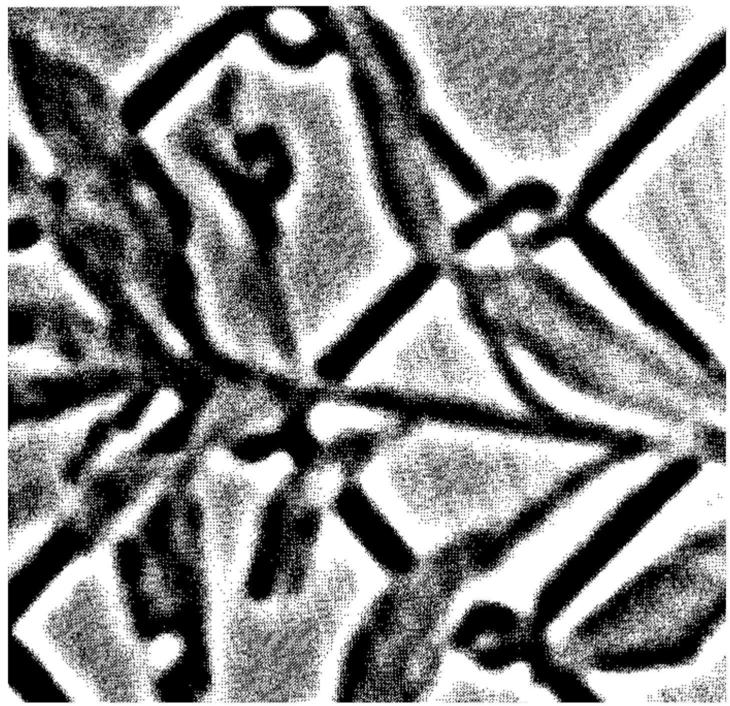
Laplacian of Gaussian



original image

Source: D. Marr and
E. Hildreth (1980)

Laplacian of Gaussian

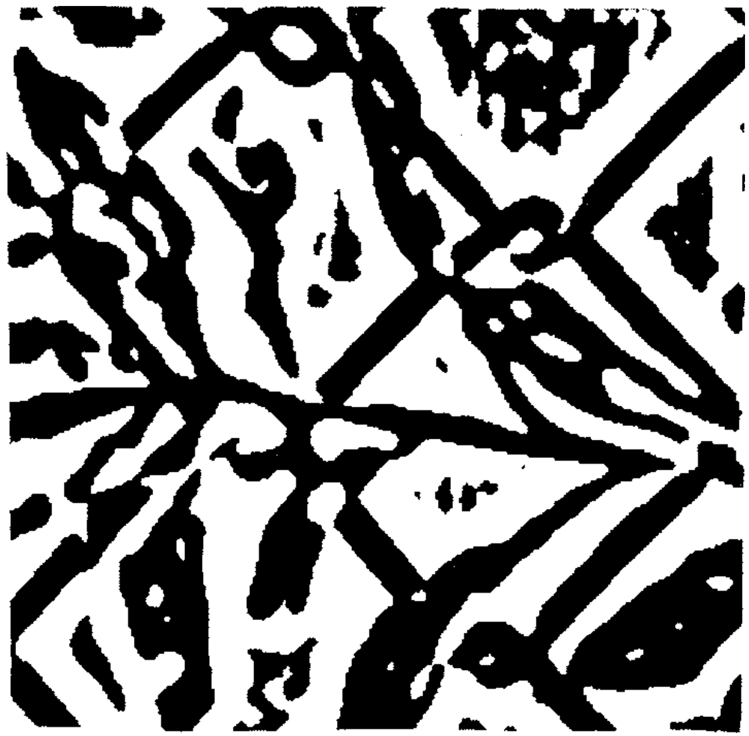


convolution with

$$\nabla^2 h_\sigma(u, v)$$

Source: D. Marr and
E. Hildreth (1980)

Laplacian of Gaussian



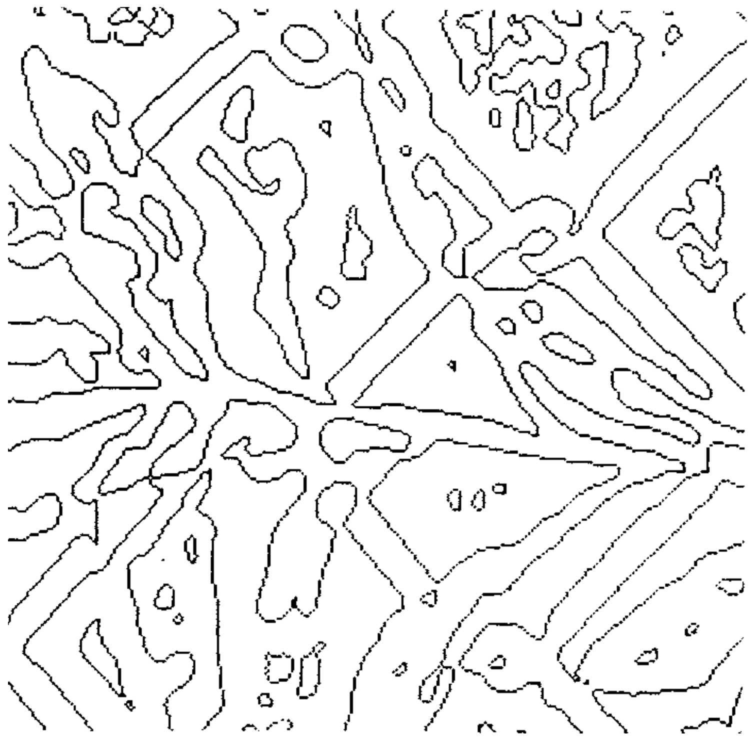
convolution with

$$\nabla^2 h_\sigma(u, v)$$

(pos. values – white, neg. values – black)

Source: D. Marr and E. Hildreth (1980)

Laplacian of Gaussian



zero-crossings

Source: D. Marr and
E. Hildreth (1980)

The Canny edge detector

original image (Lena)

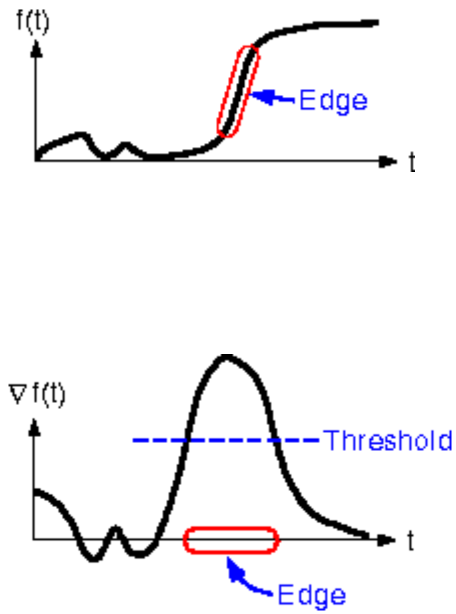
Source: K. Grauman

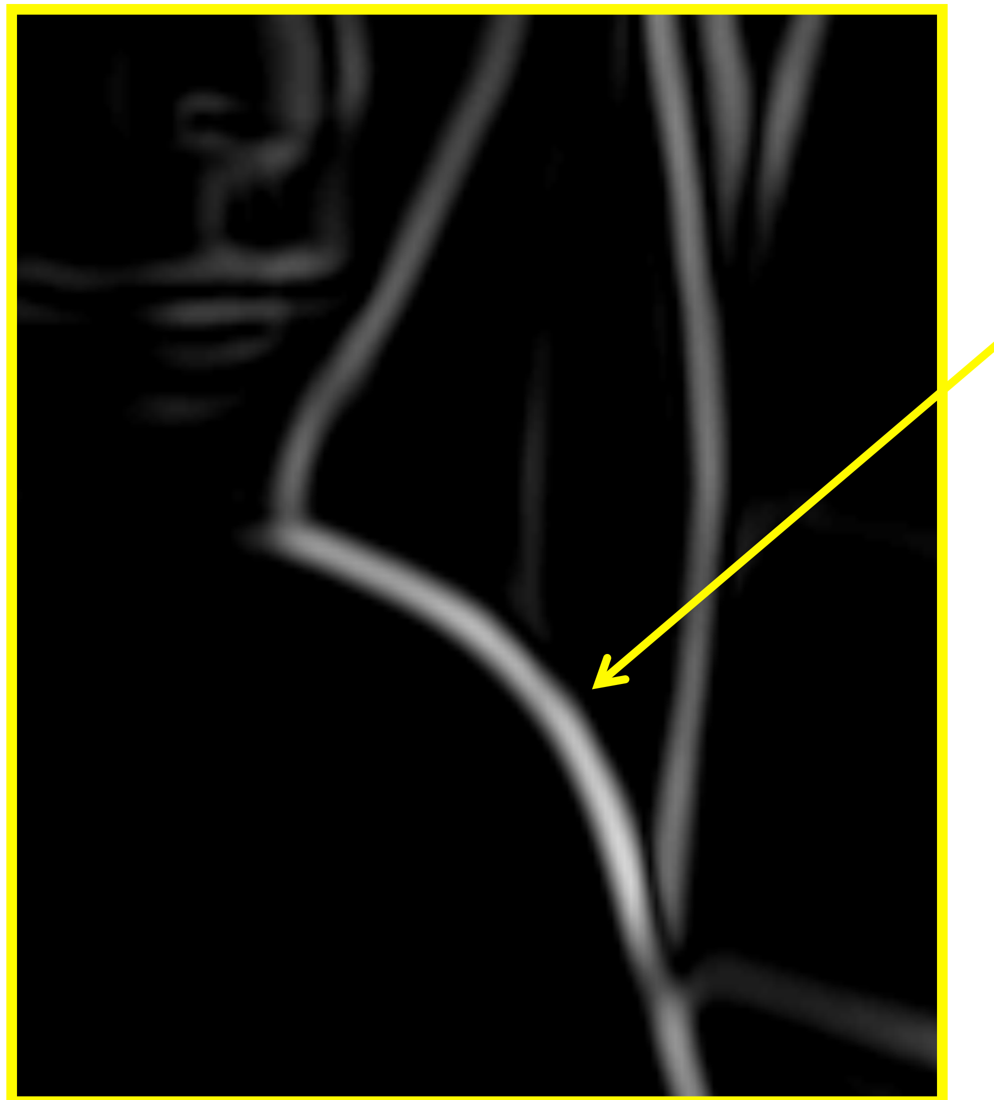
The Canny edge detector

thresholding

Source: K. Grauman

The Canny edge detector

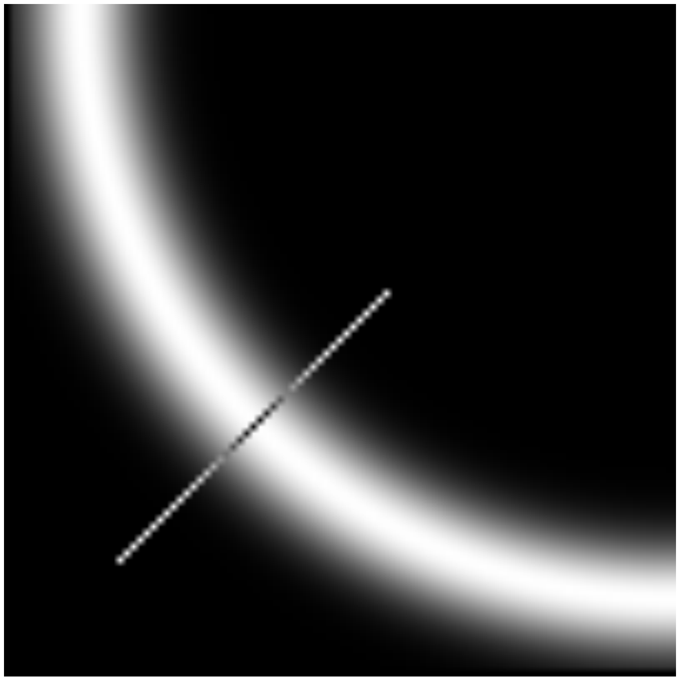


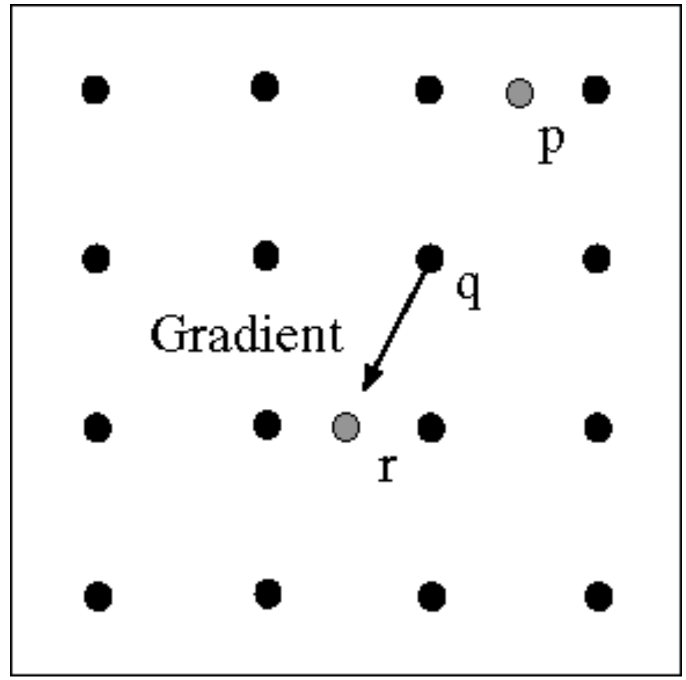


How to turn these thick regions of the gradient into curves?

Source: K. Grauman

Non-maximum suppression





Check if pixel is local maximum along gradient direction, select single max across width of the edge

- requires checking interpolated pixels p and r

Source: K. Grauman

The Canny Edge Detector

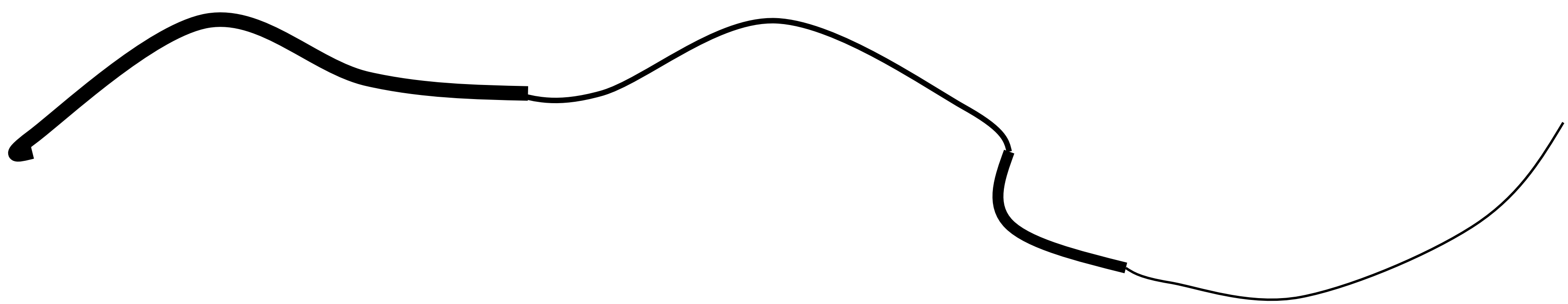
Problem: pixels along this edge didn't survive the thresholding

thinning
(non-maximum suppression)

Source: K. Grauman

Hysteresis thresholding

- Check that maximum value of gradient value is sufficiently large
  - drop-outs? use **hysteresis**
    - use a high threshold to start edge curves and a low threshold to continue them.



Source: S. Seitz

Hysteresis thresholding

original image

high threshold
(strong edges)

low threshold
(weak edges)

hysteresis threshold

Source: L. Fei-Fei