

- Localização das Bordas

Imagens com bordas realçadas por operadores diferenciais:

- Gradiente quadrado: $\propto [\delta(\cdot)]^2 \rightarrow$ Crista de altura proporcional ao quadrado da diferença de intensidade através da borda

- Laplaciano: $\propto \delta'(\cdot) \rightarrow$ Duas cristas paralelas, de polaridades opostas em cada lado da borda

- Pixels vizinhos às bordas também são realçados

- É preciso definir a localização das bordas nas imagens

- Método dos *Zero-Crossings*:

- Imagens realçadas pelo Laplaciano

- Borda pode ser localizada onde o valor da intensidade da imagem realçada muda de sinal (i.e., cruza o zero)

Para obter-se contornos em diferentes escalas, é conveniente tomar a convolução da imagem original com um operador gaussiano, antes de aplicar o laplaciano

- Escolhendo-se diferentes variâncias para a gaussiana, pode-se realçar bordas de diferentes resoluções

Temos,

$$\nabla^2[G_\sigma(x, y) * I(x, y)] = [\nabla^2 G_\sigma(x, y)] * I(x, y)$$

com

$$\nabla^2 G_\sigma(x, y) \equiv \nabla^2 G_\sigma(r) = \left(\frac{r^2 - 2\sigma^2}{2\pi\sigma^6} \right) \exp\left(\frac{-r^2}{2\sigma^2} \right)$$

onde $r = (x^2 + y^2)^{1/2}$

Assim, no domínio da frequência:

$$\mathcal{F}[\nabla^2 G_\sigma(x, y) * I(x, y)] = \mathcal{F}[\nabla^2 G_\sigma(x, y)] \mathcal{F}[I(x, y)]$$

com

$$\mathcal{F}[\nabla^2 G_\sigma(x, y)] = -\omega^2 \exp(-\sigma^2 \omega^2 / 2)$$

→ Filtro *passa-faixa* centrado na frequência $\omega = \sqrt{2}/\sigma$

- Análise no Espaço de Escala

A obtenção de contornos em diferentes resoluções, pelo método dos *zero-crossings*, é um exemplo de *análise multi-escala* ou *multinível* de imagens

Pode-se definir um *espaço de escala*, (x, y, σ) , e.g.,

$$I_\sigma(x, y) = G_\sigma(x, y) * I(x, y) \equiv I(x, y, \sigma)$$

onde $I(x, y, \sigma)$ representa a imagem no espaço de escala

Em escalas muito finas (σ pequeno) pode haver muitos detalhes espúrios, enquanto em escalas muito grosseiras (σ grande) pode-se perder características relevantes do sinal

A análise das características de $I(x, y, \sigma)$ se chama *análise no espaço de escala*



(a)



(d)



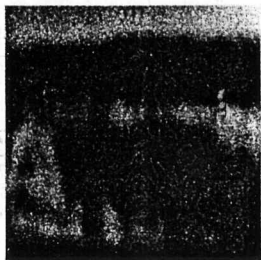
(b)



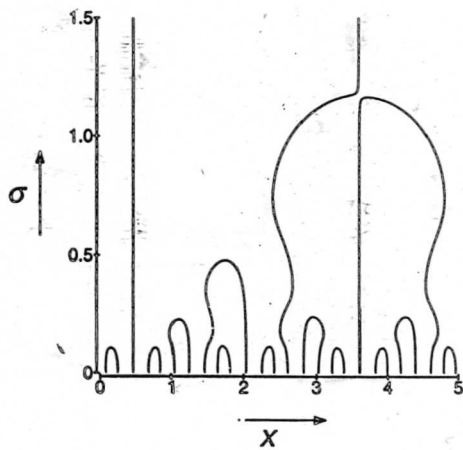
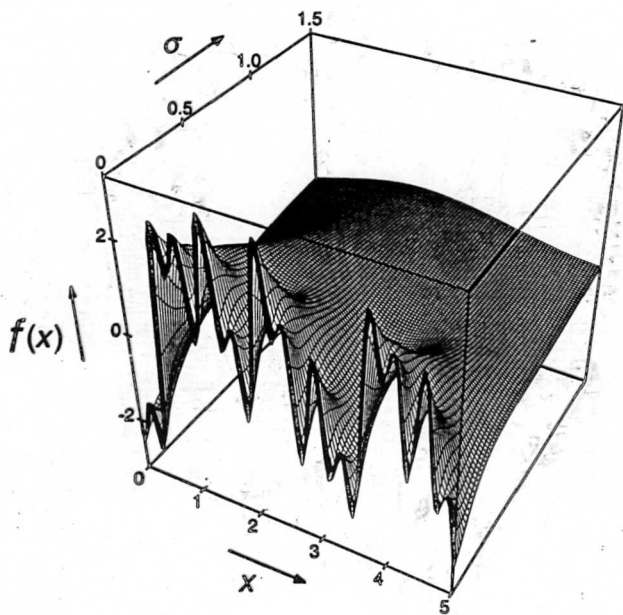
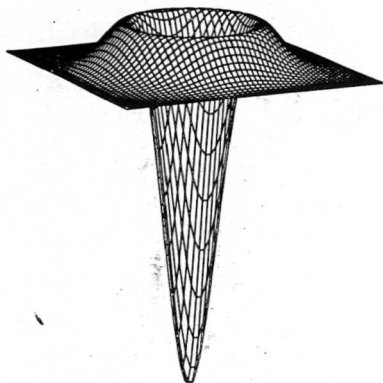
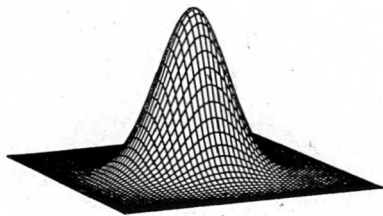
(e)



(c)



(f)



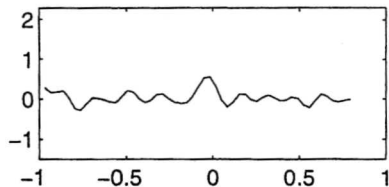
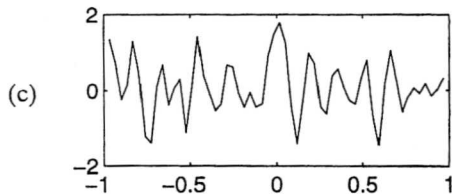
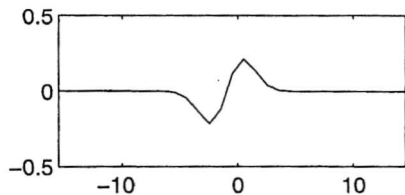
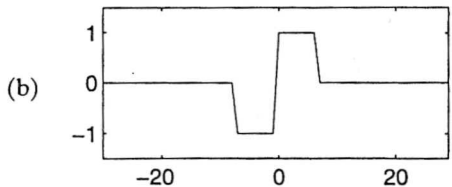
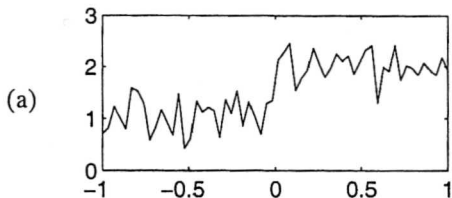
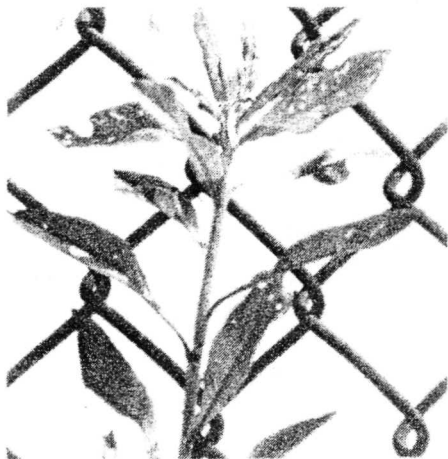
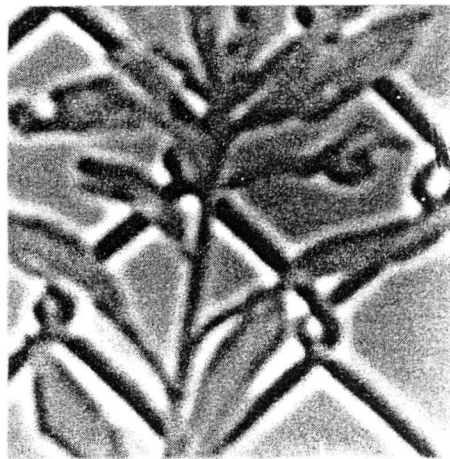


Figure 4.4 (a) Noisy, step edge, corrupted by additive Gaussian noise (standard deviation is 15% of the uncorrupted step's height). (b) The box filter (left) and the first derivative of a Gaussian (right). (c) Response to the noisy edge of the box filter (left) and of the first derivative of a Gaussian. The latter contains fewer local maxima thanks to the smoothing effect of the Gaussian. Notice the different amplitudes of the two responses due to the different amplitudes of the filters.



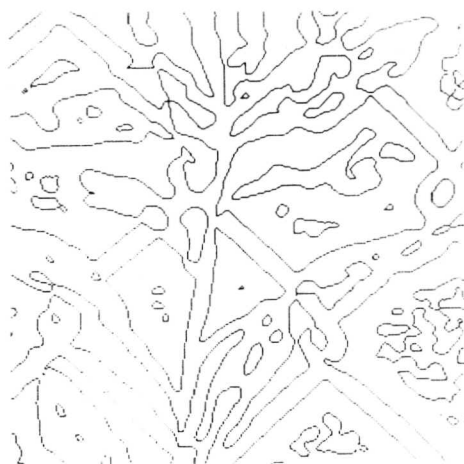
(a)



(b)



(c)



(d)

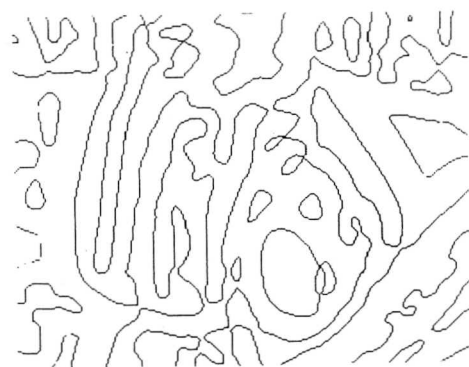
Figures 2-12, 13, 14. These three figures show examples of zero-crossing detection using $\nabla^2 G$. In each figure, (a) shows the image (320×320 pixels); (b) shows the image's convolution with $\nabla^2 G$, with $w_{2-10} = 8$ (zero is represented by gray); (c) shows the positive values in white and the negative in black; (d) shows only the zero-crossings.



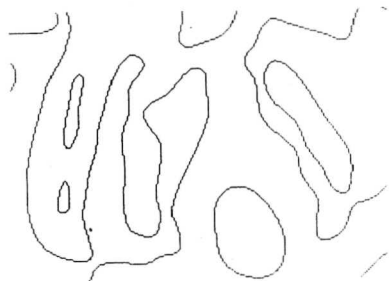
(a)



(b)



(c)



(d)

Figure 2-20. The image (a) has been convolved with $\nabla^2 G$ having $w_{2-D} = 2\sqrt{2}\sigma = 6, 12,$ and 24 pixels. These filters span approximately the range of filters that operate in the human fovea. (b), (c), and (d) show the zero-crossings thus obtained. Notice the fine detail picked up by the smallest. This set of figures neatly poses the next problem—How do we combine all this information into a single description? (Reprinted by permission from D. Marr and E. Hildreth, "Theory of edge detection," *Proc. R. Soc. Lond. B* 204, pp. 301–328.)