Edge Detection & Image Sharpening

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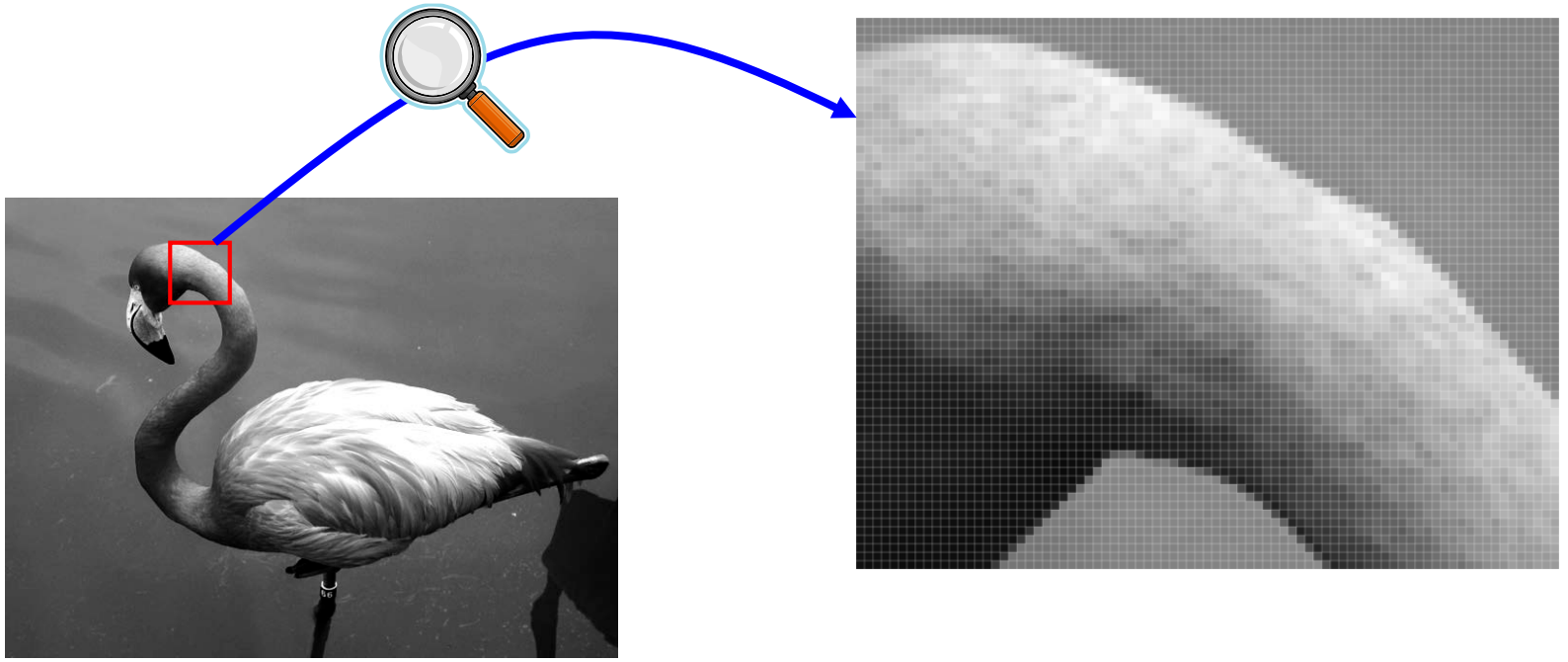
학습 내용

- Edge 정의
- Edge detection 개요 및 방법
- Image sharpening 방법

Edge 정의

A large change in image brightness over a short spatial distance



Edge detection 개요

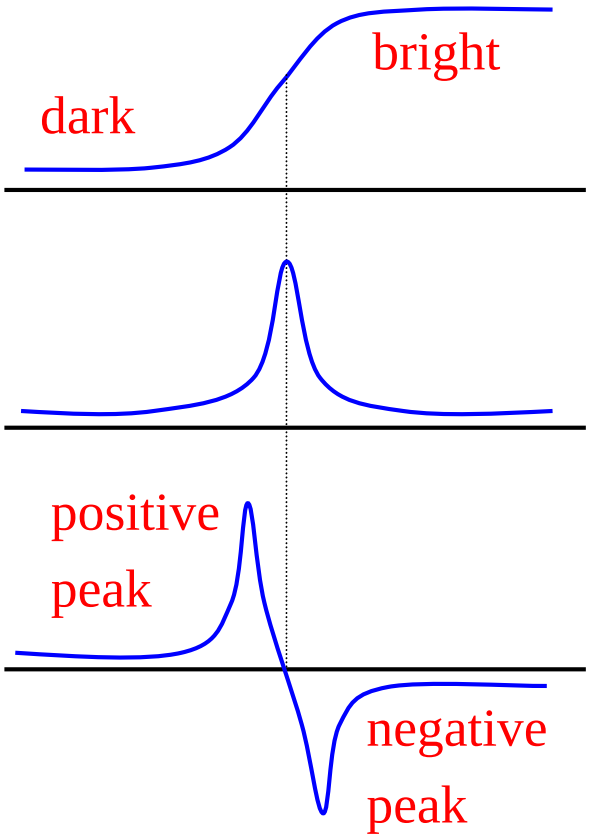
Most are based on **discrete approximations to differential operators**

Implemented with convolution masks

Return orientation or existence of an edge information

Used as a first step in the line detection or object outlines process

Edge detection 방법



change of brightness

1st–order derivative

Prewitt, Sobel, Roberts 등

2nd–order derivative

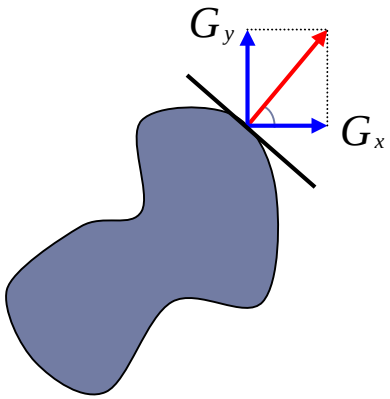
Laplacian

1st–order derivative

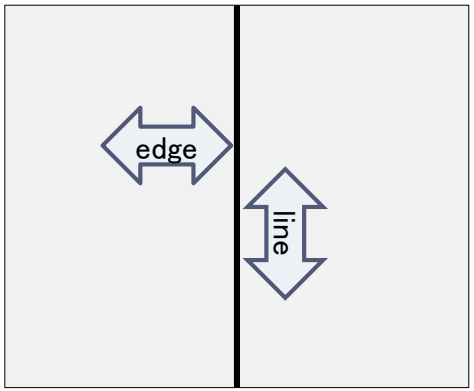
$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

$$G_x \cong f[x+1, y] - f[x, y], \quad G_y \cong f[x, y+1] - f[x, y]$$

$$G = \sqrt{G_x^2 + G_y^2} \approx |G_x| + |G_y| \approx \max(|G_x| , |G_y|)$$



$$\alpha(x, y) = \tan^{-1}\left(\frac{G_y}{G_x}\right)$$



Prewitt

$$G_x \cong f[x+1, y] - f[x, y], \quad G_y \cong f[x, y+1] - f[x, y]$$

$$G_x = h_x(x, y) * f(x, y), \quad G_y = h_y(x, y) * f(x, y)$$

$$h_x(x, y) = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad h_y(x, y) = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$\Updownarrow$$

$$\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \cdot \begin{bmatrix} -1 & 0 & 1 \end{bmatrix}$$

Finite diff filter

Simple box filter

Sobel

$$G_x \cong f[x+1,y]-f[x,y],\quad G_y \cong f[x,y+1]-f[x,y]$$

$$G_x = h_x(x,y) * f(x,y),\quad G_y = h_y(x,y) * f(x,y)$$

$$h_x(x,y)=\begin{bmatrix}-1 & 0 & 1\\ -2 & 0 & 2\\ -1 & 0 & 1\end{bmatrix} \qquad h_y(x,y)=\begin{bmatrix}-1 & -2 & -1\\ 0 & 0 & 0\\ 1 & 2 & 1\end{bmatrix}$$

$$\downarrow$$

$$\begin{bmatrix}1\\ 2\\ 1\end{bmatrix}\cdot\begin{bmatrix}-1 & 0 & 1\end{bmatrix}$$

Finite diff filter

Simple Gaussian filter

Roberts

$$G_x \cong f[x+1,y]-f[x,y],\quad G_y \cong f[x,y+1]-f[x,y]$$

$$G_x = h_x(x,y) * f(x,y),\quad G_y = h_y(x,y) * f(x,y)$$

$$h_x(x,y)=\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix} \qquad h_y(x,y)=\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

No the orientation information

(a) 원영상

(b) Prewitt

(c) Sobel

(d) Roberts

Laplacian

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

$$\frac{\partial^2 f}{\partial x^2} = \frac{\partial G_x}{\partial x} = \frac{\partial(f[x+1,y] - f[x,y])}{\partial x} = \frac{\partial f[x+1,y]}{\partial x} - \frac{\partial f[x,y]}{\partial x}$$

$$= (f[x+1,y] - f[x,y]) - (f[x,y] - f[x-1,y]) = f[x+1,y] - 2f[x,y] + f[x-1,y]$$

$$\frac{\partial^2 f}{\partial y^2} = f[x,y+1] - 2f[x,y] + f[x,y-1]$$

$$\nabla^2 f = \left[f(x,y+1) + f(x-1,y) + f(x+1,y) + f(x,y-1) \right] - 4f(x,y)$$

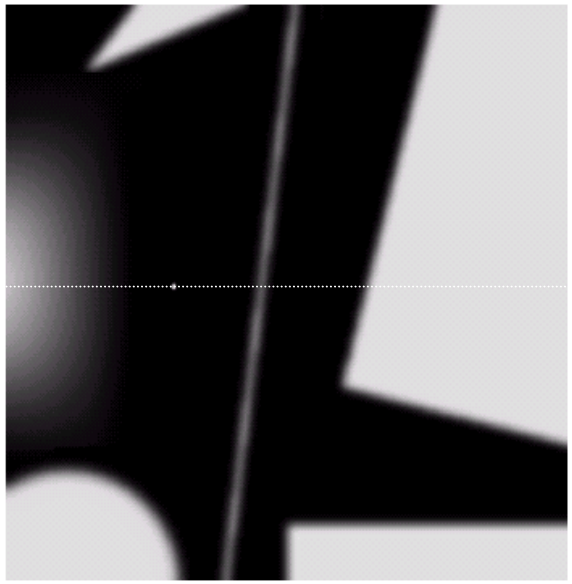
$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

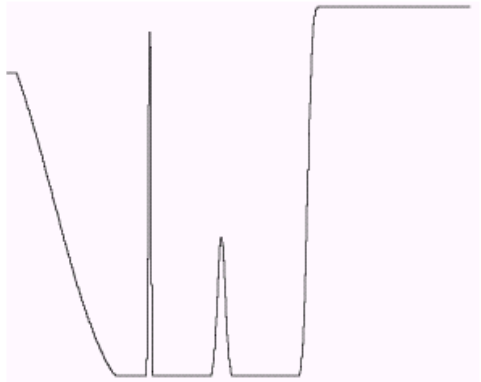
common spatial convolution masks

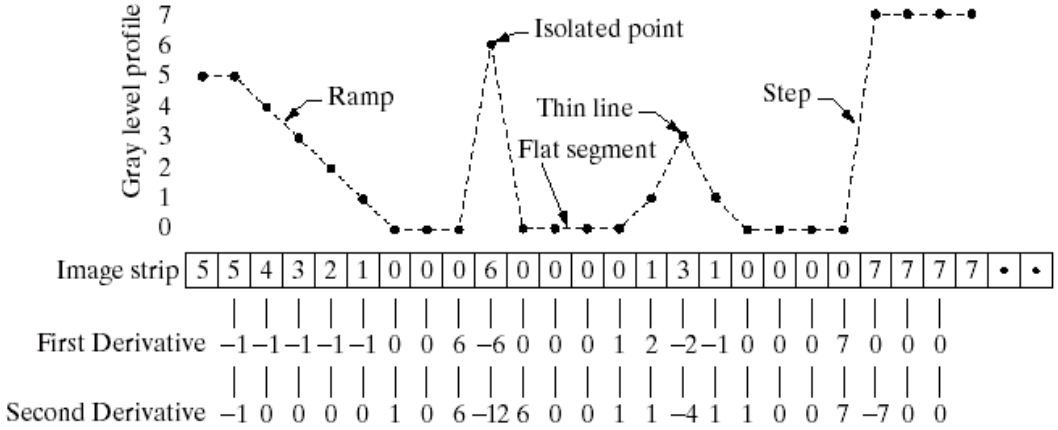
First vs. Second-order derivative

a b
c

FIGURE 3.38
(a) A simple image. (b) 1-D horizontal gray-level profile along the center of the image and including the isolated noise point.
(c) Simplified profile (the points are joined by dashed lines to simplify interpretation).







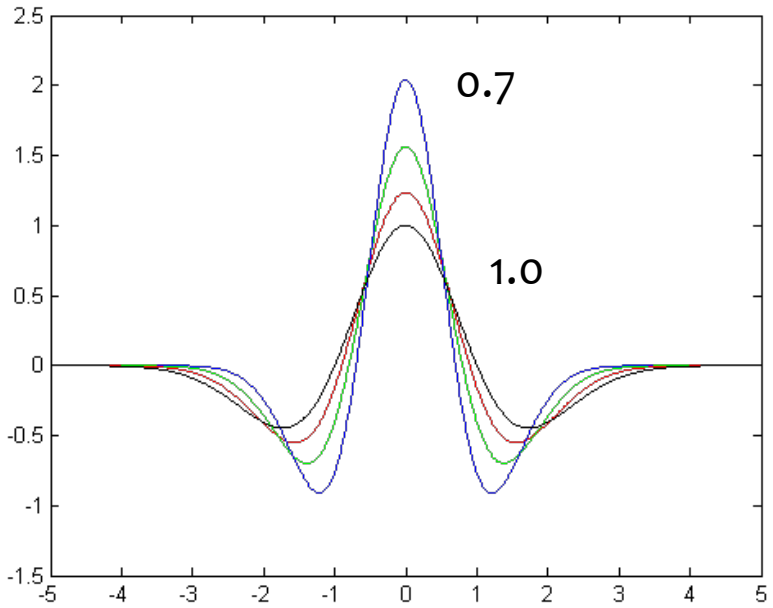
- First-order derivatives generally produce **thicker** edges
- Second-order derivatives have a **stronger** response to fine detail, such as thin lines and isolated points
- First-order derivatives generally have a **stronger** response to a gray-level step
- Second-order derivatives produce a **double response** at step changes in gray level

➔ In most applications, **the second-order derivative is better suited** than the first derivative for image enhancement

Laplacian of Gaussian filtering

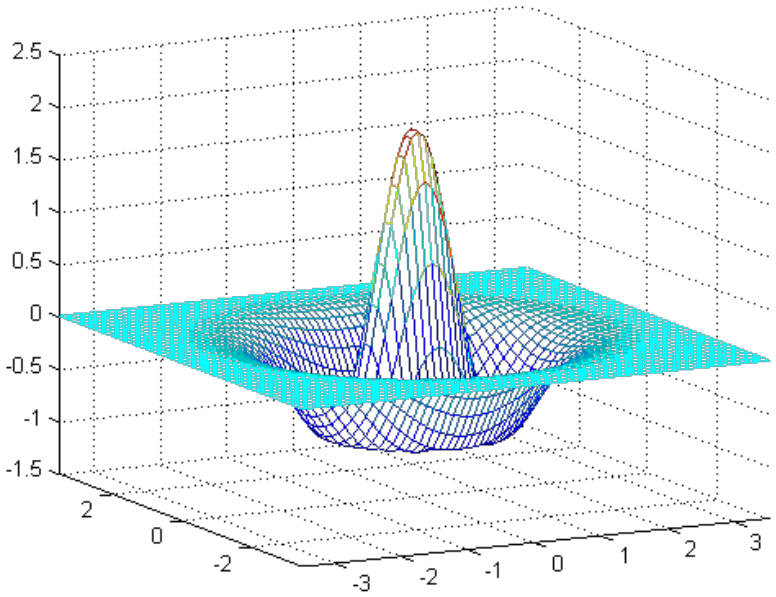
$$g(x,y) = \left[\nabla^2 h(x,y)\right] * f(x,y)$$

$$\nabla^2 h(x,y) = -\left(\frac{x^2 + y^2 - \sigma^2}{\sigma^4}\right) e^{-\frac{\left(x^2+y^2\right)}{2\sigma^2}}$$



0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

LoG mask



(a) 원영상

(b) 4 방향
라플라시안

(c) 8 방향
라플라시안

(d) 가우시안의
라플라시안

Image Sharpening

enhancing detail information in an image

typically contained in the *high spatial frequency* components of the image

done by various types of high boost filters and Laplacian-type filters

High-pass filtering

$$f_H(x,y) = f(x,y) - f_L(x,y)$$

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} = \frac{1}{9} \times \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

10	10	10	10	10	10	10	10
10	20	20	20	10	10	10	10
10	20	30	20	10	10	10	10
10	20	20	20	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10

High-pass filtering

-10	-20	-10	-20	-10	0	0	0
-20	40	20	40	-20	0	0	0
-30	20	80	20	-30	0	0	0
-20	40	20	40	-20	0	0	0
-10	-20	-30	-20	-10	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

※ 이전 슬라이드의 마스크에서
9로 나누는 것을 제외하고 계산
※ 경계외부는 경계 값으로 채움

High boost filtering

$$
\begin{aligned}
g(x,y) &= Af(x,y) - f_L(x,y) \\
&= \{(A-1)f(x,y)\} \\
&\quad + \{f(x,y) - f_L(x,y)\} \\
&= (A-1)f(x,y) + f_H(x,y)
\end{aligned}
$$

$$
f_L = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix},
$$

$$
A\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} = \frac{1}{9}\begin{bmatrix} -1 & -1 & -1 \\ -1 & 9A-1 & -1 \\ -1 & -1 & -1 \end{bmatrix} \Rightarrow \begin{bmatrix} -1 & -1 & -1 \\ -1 & \alpha & -1 \\ -1 & -1 & -1 \end{bmatrix}
$$

High boost

$$
\therefore \alpha = 9A - 1 (A \geq 1)
$$

결과영상(α=9)

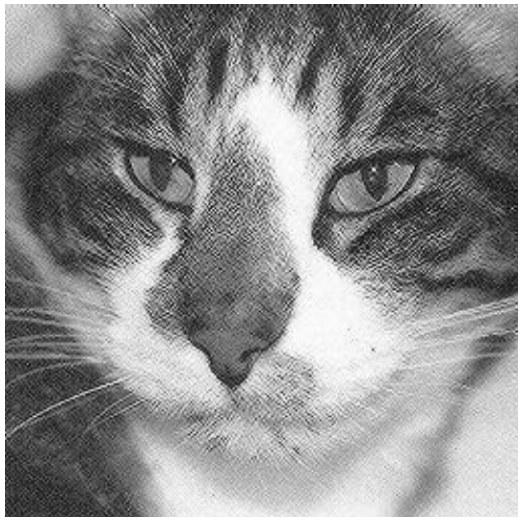
Histogram equalization

Laplacian-type filtering

$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

$$\begin{bmatrix} 1 & -2 & 1 \\ -2 & 5 & -2 \\ 1 & -2 & 1 \end{bmatrix}$$

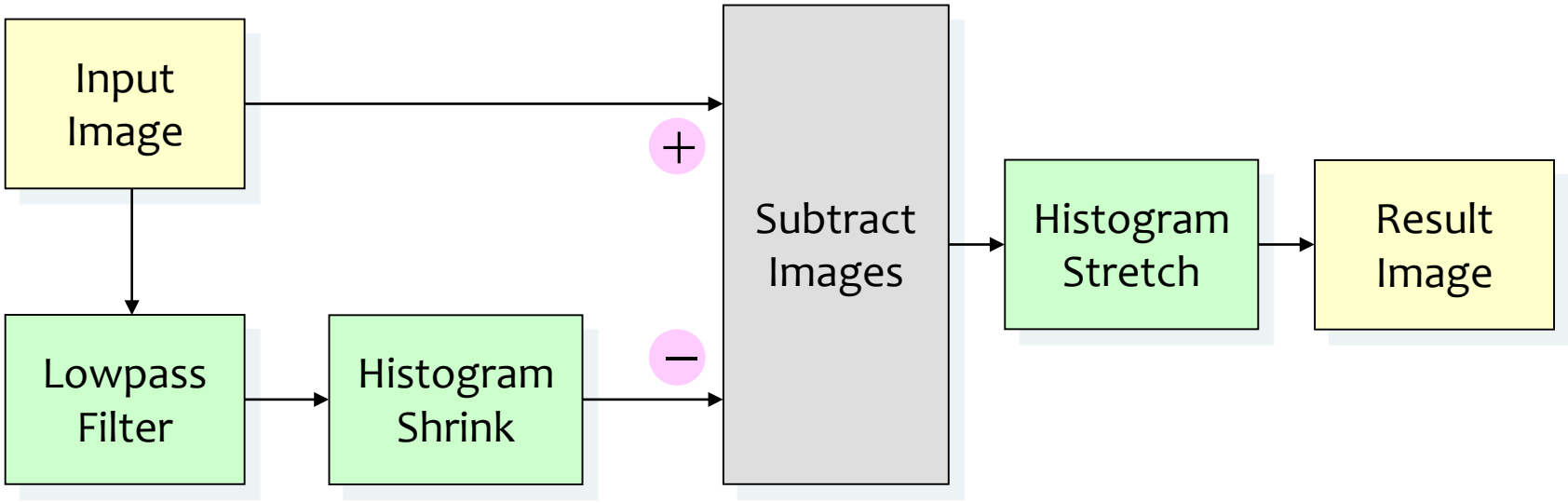
Original image



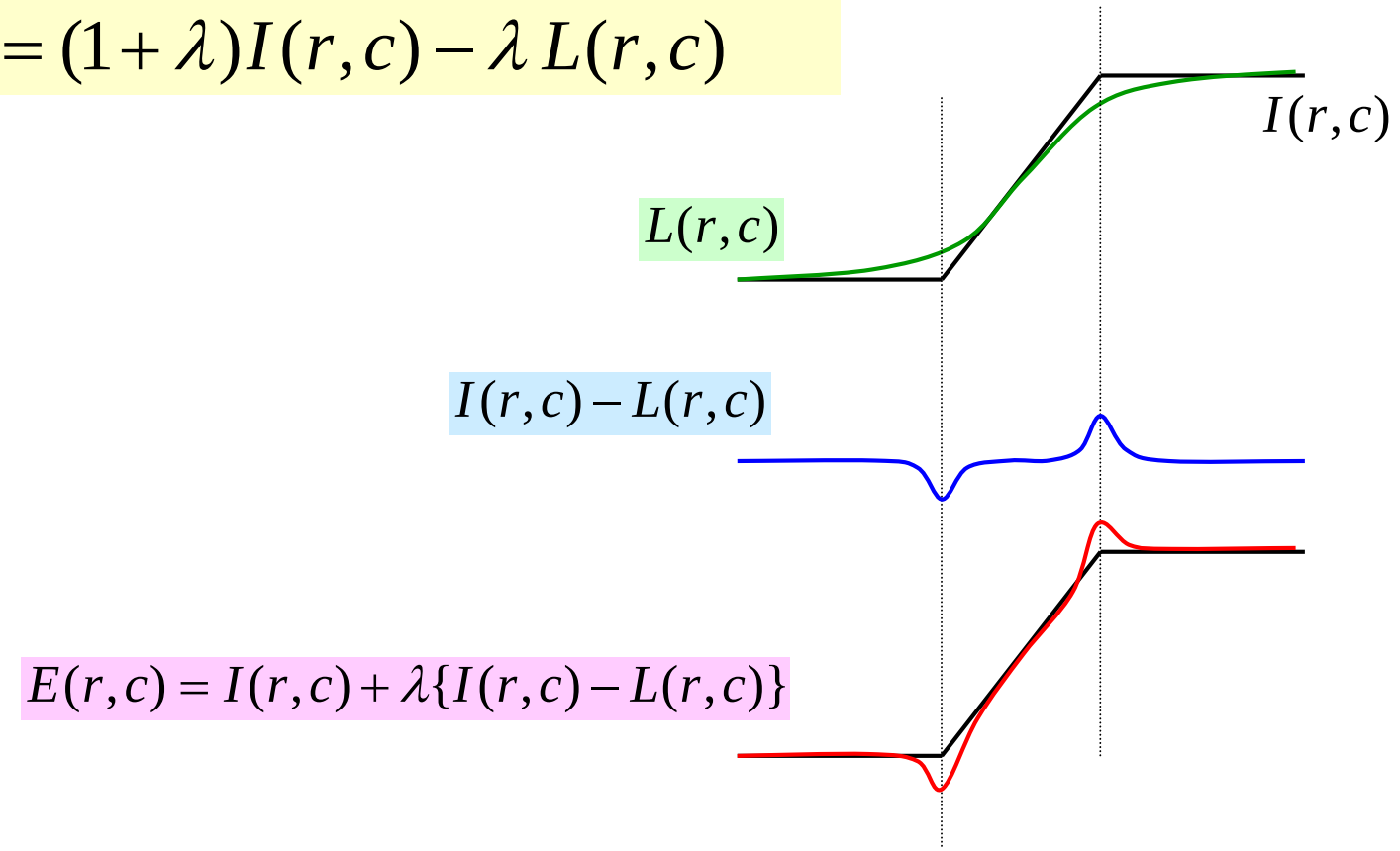
Contrast-enhanced

$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

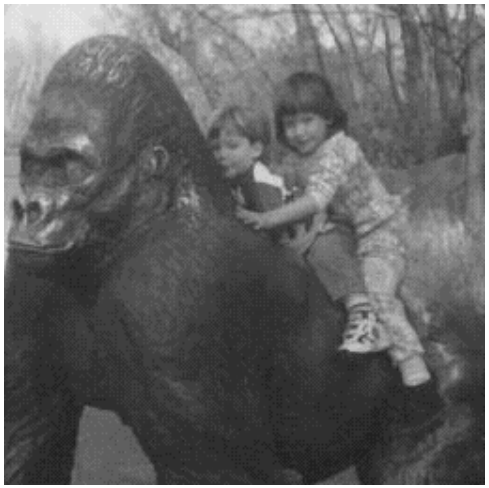
Unsharp masking



$$E(r,c) = I(r,c) + \lambda H(r,c)$$
$$= I(r,c) + \lambda\{I(r,c) - L(r,c)\}$$
$$= (1+\lambda)I(r,c) - \lambda L(r,c)$$



Original Image



Unsharp masking
lower limit=0,
upper=100,
2% low and
high clipping

Unsharp masking
lower limit=0,
upper=150,
2% low and
high clipping

Unsharp masking
lower limit=0,
upper=200,
2% low and
high clipping

요약

- Edge
  - 짧은 공간적인 거리상에서 영상의 밝기 혹은 색상이 급격하게 변하는 지점
- Edge detection 개요
  - 주로 차분 연산을 이산적으로 근사화하여 사용 (마스크 사용 처리)
  - Edge의 세기와 방향을 제공
- Edge detection 방법
  - 1차 미분: Prewitt, Sobel, Roberts 등
  - 2차 미분: Laplacian (Laplacian of Gaussian)

- Image Sharpening
  - 영상의 상세 정보를 강화
  - High-pass filtering, High boost filtering, Laplacian-type filtering, Unsharp masking

Reference

- R. Gonzalez, R. Woods, **Digital Image Processing (2nd Edition),** Prentice Hall, 2002
- Scott E Umbaugh, **Computer Imaging**, CRC Press, 2005