Computer Vision and Deep Learning

Ch 04

강명묵

Contents

Edge Detection

Edge Detection : 윤곽선을 검출하는 기술로써, 영상에서 객체의 경계를 찾기 위한 기법
Edge Operator : 이미지에서 **Edge Position, magnitude, orientation**을 추출하는데 활용된다.

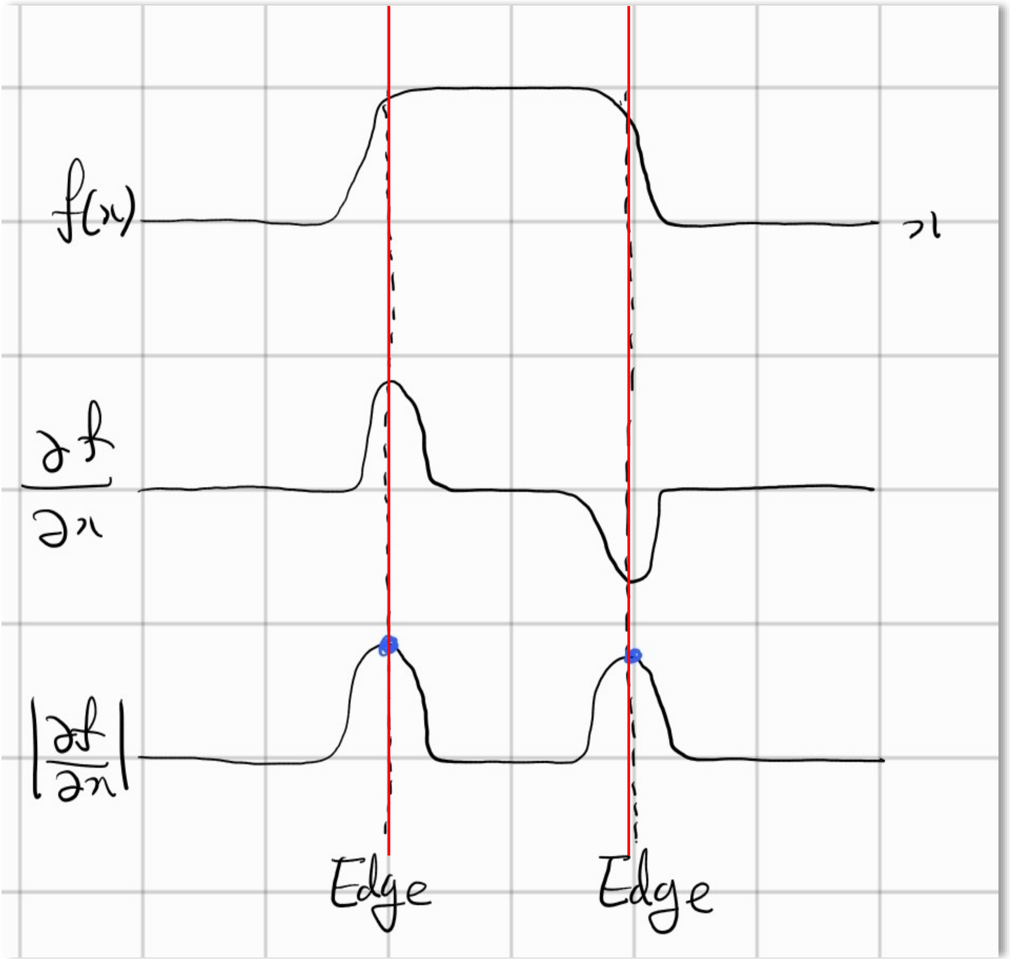
Three performance criteria in Canny Edge Detection

1. Good Detection
Edge point의 marking 실패율을 낮출수록 좋다.
(SNR을 올릴수록 좋음)

2. Good Localization
Edge로 판단한 지점과 실제 Edge의 중심이 가까울 수록 좋다.

3. Only one response to a single Edge
Edge에 대해 단 하나의 응답을 해야 한다.
(NMS 적용)

1D Edge Detection



Gradient(∇)

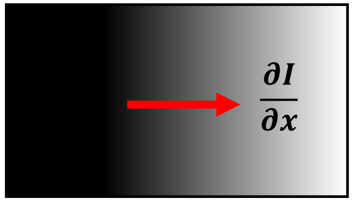
1. Edge의 크기와 방향, 위치를 얻어낼 수 있다.

2. Edge 검출에 용이한 Threshold를 찾아야 한다.

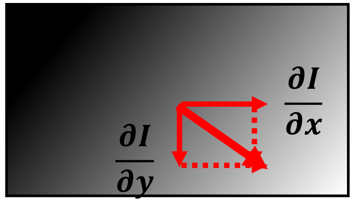
3. Convolution을 두 번 수행한다.
x축, y축

4. non-linear operatior이다.
각 픽셀에 대한 미분 값이 픽셀 값 자체에 의존하기 때문

2D Edge Detection



$$\nabla I = [\frac{\partial I}{\partial x}, 0]$$



$$\nabla I = [\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}]$$

Gradient Magnitude

$$S = \|\nabla I\| = \sqrt{(\frac{\partial I}{\partial x})^2 + (\frac{\partial I}{\partial y})^2}$$

Gradient Orientation

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

Discrete Gradient(∇) Operator

$$f'(x) = \frac{\lim_{\partial x \to 0} \frac{f(x+\partial x) - f(x)}{\partial x} + \lim_{\partial x \to 0} \frac{f(x) - f(x-\partial x)}{\partial x}}{2}$$

↳ 영상처리에서는 Discrete!

$$\Rightarrow f'(x) = \frac{f(x+1) - f(x) + f(x) - f(x-1)}{2} = \frac{1}{2}\left(f(x+1) - f(x-1)\right)$$

→ 픽셀간의 상대적인 기울기가 중요한 것이지 기울기의 크기가 중요한 것은 아님.

→ $f(x+1) - f(x-1)$을 구현하는 필터 ⇒

-1	0	1

1nd derivative

Discrete Gradient(∇) Operator

-1	0
0	1

Roberts_x

↕ Orthogonal!

0	-1
1	0

Roberts_y

-1	0	1
-1	0	1
-1	0	1

Prewitt_x

-1	-1	-1
0	0	0
1	1	1

Prewitt_y

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

Sobel_x

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

Sobel_y

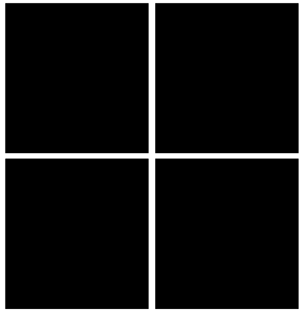
Discrete Gradient(∇) Operator

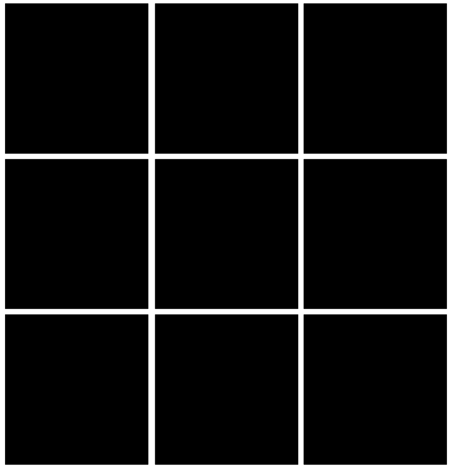
Filter size

小 → 大

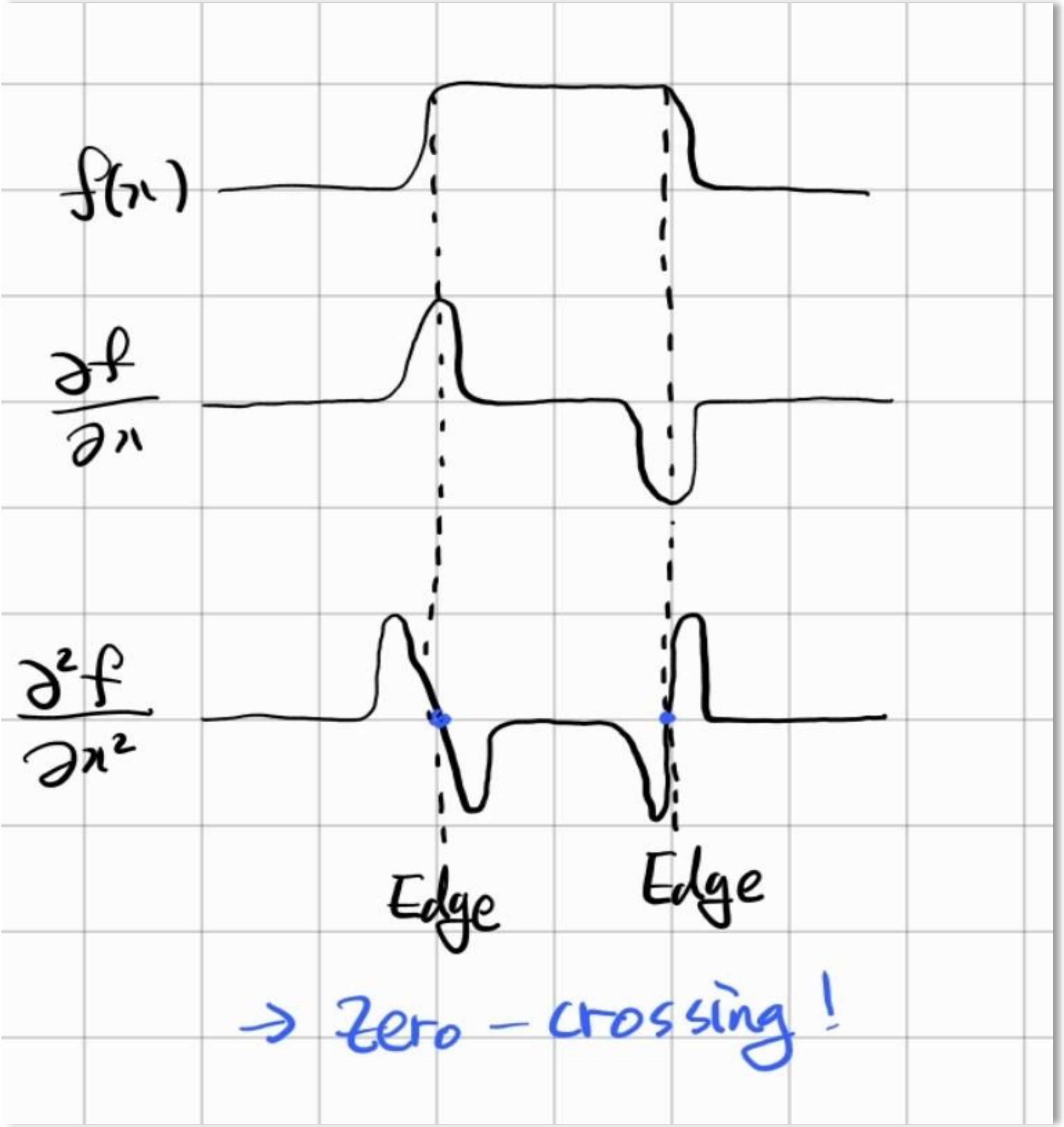
Good Localization
Noise Sensitive
Poor Detection

Poor Localization
Less Noise Sensitive
Good Detection





Discrete Laplacian(∇^2) Operator



Laplacian(∇^2)

1. Edge의 위치를 얻어낼 수 있다.

2. Zero-Crossing
모든 기울기의 합이 0이다.

3. Convolution을 한 번 수행한다.

4. Linear-operator이다.
Laplacian은 주변 픽셀에 대한 합으로 나타낼 수 있고, 이 합의 계수는 고정된 상수이기 때문

Discrete Laplacian(∇^2) Operator

$f'(x) = \frac{f(x+\delta) - f(x)}{\delta} = f(x+1) - f(x)$

대입.

$f''(x) = \frac{f'(x) - f'(x-\delta)}{\delta} = f'(x) - f'(x-1)$

$= f(x+1) - 2f(x-1) + f(x)$

filter $\Rightarrow$

1	-2	1

2^{nd} derivative

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

0	0	0
1	-2	1
0	0	0

+

0	1	0
0	-2	0
0	1	0

∇^2 =

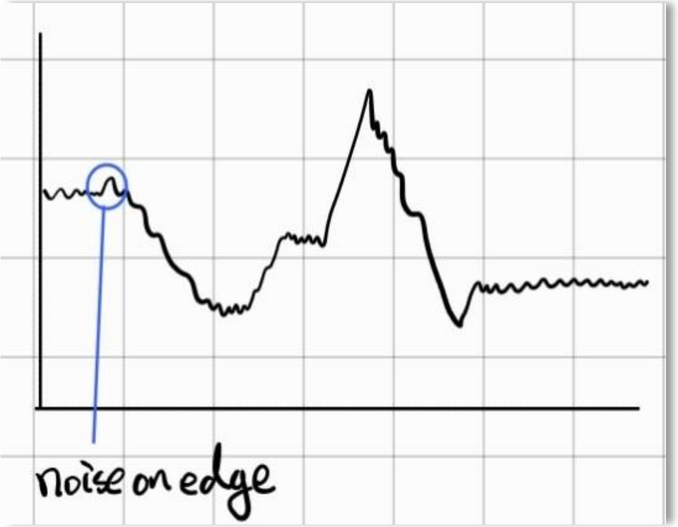
0	1	0
1	-4	1
0	1	0

정확성↑

$\nabla^2 = \frac{1}{6}$

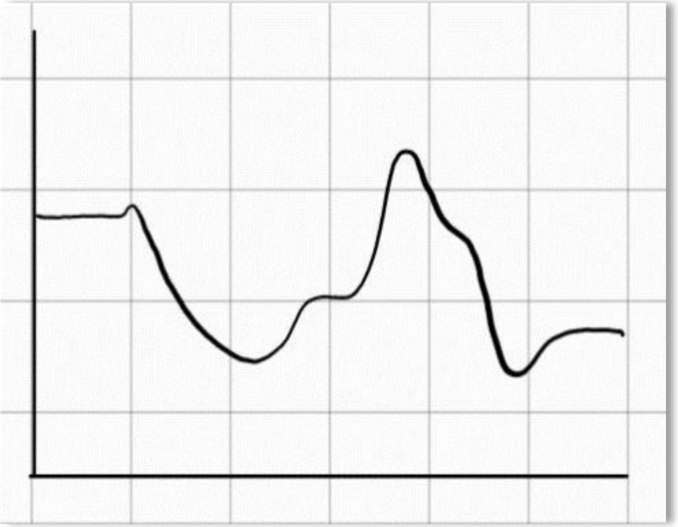
1	4	1
4	-20	4
1	4	1

Operator Application



f

Noise때문에 어디서든 **기울기가 빠르게 변화**한다.

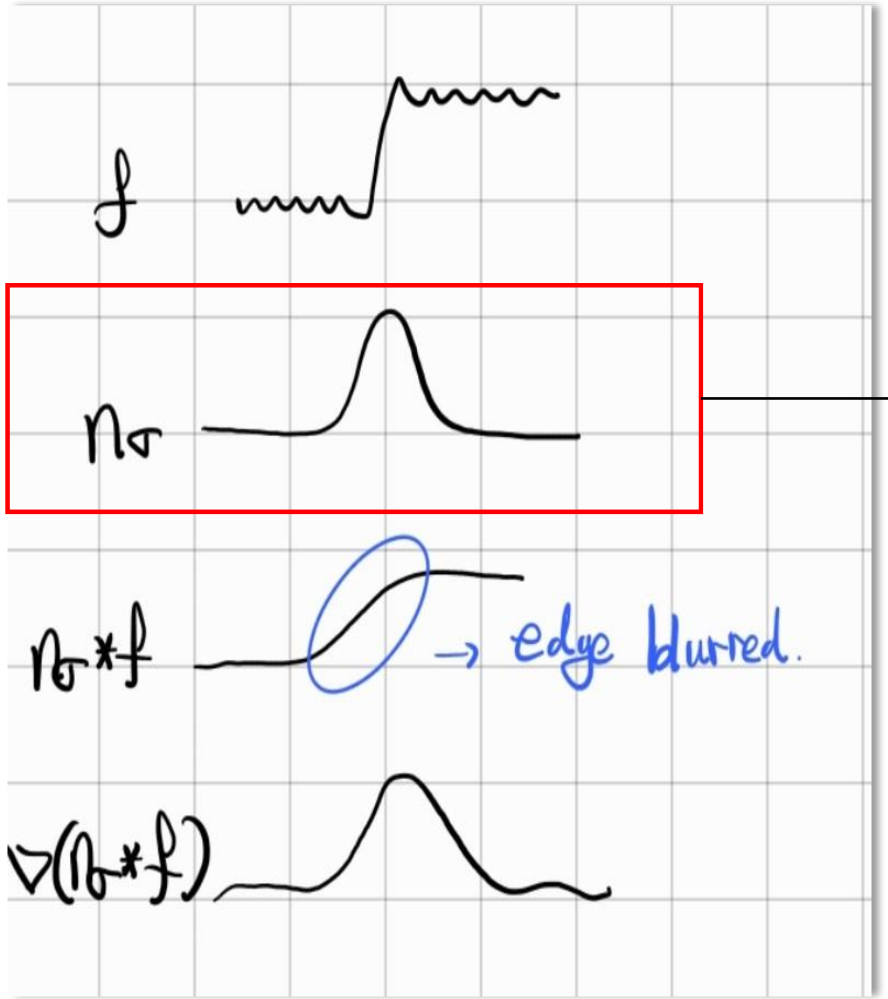


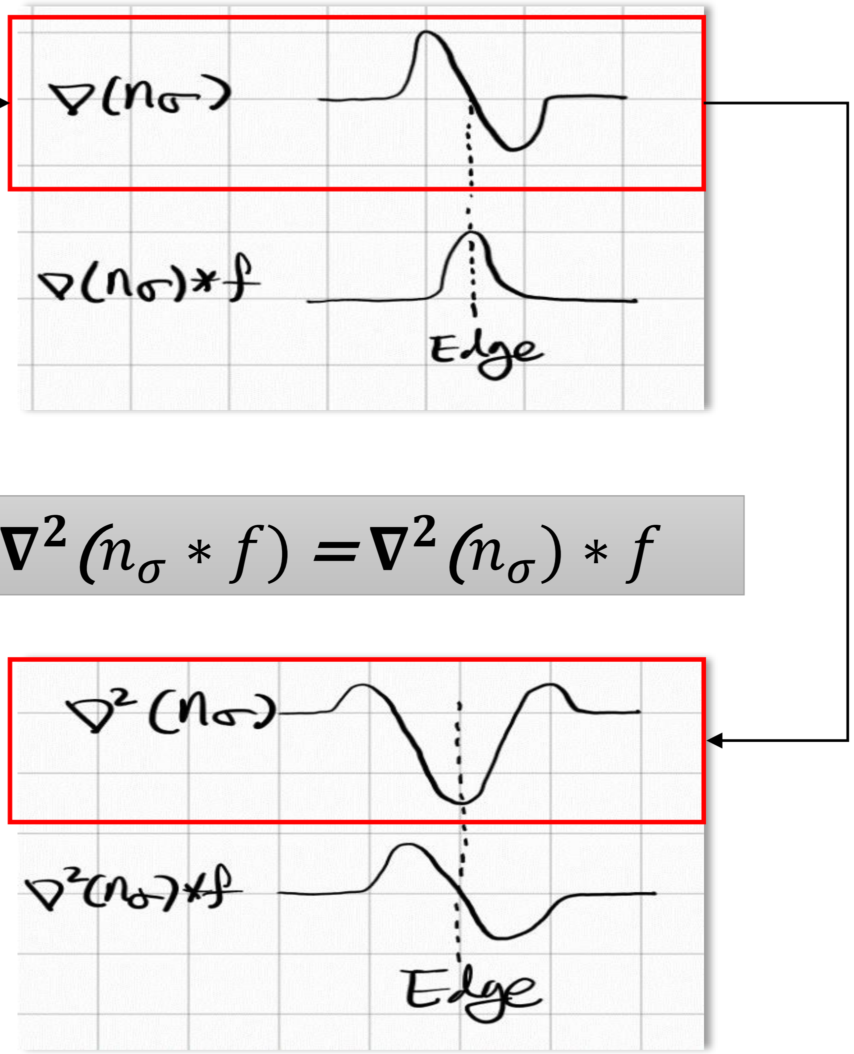
$n_\sigma * f$

가우시안 스무딩을 통해 노이즈 완화

Operator Application

$$\nabla(n_\sigma * f) = \nabla(n_\sigma) * f$$





$$\nabla^2(n_\sigma * f) = \nabla^2(n_\sigma) * f$$

Canny Edge Detector

Canny Edge Detector
최소 오류율, 위치 정확도, 한 두께라는 기준에 따라 목적 함수를 정의한 에지 검출 최적화 기법

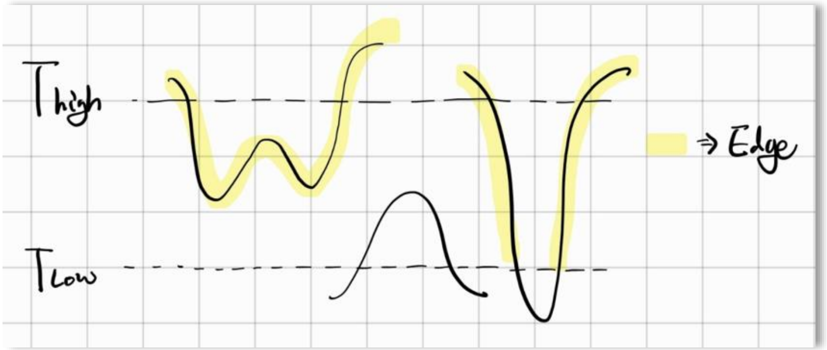
Non-Maximum Suppression

한 두께 에지를 출력하기 위한 기법이다.
에지 방향에 수직인 두 이웃 화소의 에지보다 크면 에지로 살아남고, 그렇지 않으면 억제한다.

Hysteresis thresholding

$\|\nabla I(x,y)\| < T_{Low}$: not Edge
$\|\nabla I(x,y)\| > T_{high}$: Edge

Then, $T_{Low} < \|\nabla I(x,y)\| < T_{high}$ **?**



Canny Edge Detector

Algorithm

1. $\boldsymbol{n_\sigma * I}$
2D Gaussian 필터를 이용하여 이미지를 **스무딩**

2. $\boldsymbol{\nabla n_\sigma * \mathbf{I}}$
Sobel 연산자를 이용하여 **Gradient**를 구한다.

Gradient **magnitude** : $\|\nabla \boldsymbol{n_\sigma} * \mathbf{I}\,\|$

Gradient **orientation** : $\hat{\boldsymbol{n}} = \frac{\nabla \boldsymbol{n_\sigma} * \mathbf{I}}{\|\nabla \boldsymbol{n_\sigma} * \mathbf{I}\,\|}$

3. Non-maximum suppression
두꺼운 에지 제거

4. Hysteresis thresholding
최종 에지 선정 ($\boldsymbol{T_{high}}$는 $\boldsymbol{T_{low}}$의 2~3배 설정)

Canny Edge Detector

Step 1.

2D Gaussian 필터를 이용하여 이미지를 **스무딩**$(\boldsymbol{n_\sigma} * \boldsymbol{I})$

```
Mat Gaussian_Kernel(int size, float sigma) {
  Mat kernel(size, size, CV_32F);

  int kernelCenter = (size - 1) / 2;
  float sum = 0.0;

  for (int i = 0; i < size; i++) {
    for (int j = 0; j < size; j++) {
      int x = kernelCenter - i;
      int y = kernelCenter - j;
      kernel.at<float>(i, j) = exp(-(static_cast<float>(x * x) +
        static_cast<float>(y * y)) / (2.0 * sigma * sigma)) / sqrt(2.0 * PI * sigma * sigma);
      sum += kernel.at<float>(i, j);
    }
  }

  kernel /= sum;
  return kernel;
}
```

```
Mat conv(Mat& img, Mat& kernel) {
  int kernelCenter = (kernel.rows - 1) / 2;
  Mat img_conv(img.cols - 2 * kernelCenter, img.rows - 2 * kernelCenter, CV_32F);

  for (int i = kernelCenter; i < img.rows - kernelCenter; i++) {
    for (int j = kernelCenter; j < img.cols - kernelCenter; j++) {
      float value = 0;
      for (int m = 0; m < kernel.rows; m++) {
        for (int n = 0; n < kernel.cols; n++) {
          value += static_cast<float>(img.at<uchar>(i - kernelCenter + m,
            j - kernelCenter + n)) * kernel.at<float>(m, n);
        }
      }

      img_conv.at<float>(i - kernelCenter, j - kernelCenter) =value;
    }
  }

  return img_conv;
}
```

Gaussian filter σ = 1, size = 3x3

Canny Edge Detector

Step 2.
Sobel 연산자를 이용하여 **Gradient**를 구한다.

Gradient **magnitude :** $\|\nabla n_\sigma * \mathbf{I}\,\|$

Gradient **orientation :** $\hat{n} = \dfrac{\nabla n_\sigma * \mathbf{I}}{\|\nabla n_\sigma * \mathbf{I}\,\|}$

```
Mat Sobel_operator(int x) {
    Mat sobelKernelX = (Mat_<float>(3, 3) << -1, 0, 1,  -2, 0, 2,  -1, 0, 1);
    Mat sobelKernelY = (Mat_<float>(3, 3) << -1, -2, -1, 0, 0, 0,  1, 2, 1);
    if (x == 1) return sobelKernelX;
    else return sobelKernelY;
}
```

Sobel_x

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

Sobel_y

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

Sobel_combined

```
Mat weight_x_y(Mat& img_x, Mat& img_y, float weight) {
    Mat img_w = Mat::zeros(img_x.rows, img_x.cols, CV_32F);
    for (int x = 0; x < img_x.cols; ++x) {
        for (int y = 0; y < img_y.rows; ++y) {
            img_w.at<float>(y,x) = img_x.at<float>(y, x) * weight + img_y.at<float>(y, x) * (1 - weight);
        }
    }
    return img_w;
}
```

Gradient의 크기와 방향 계산

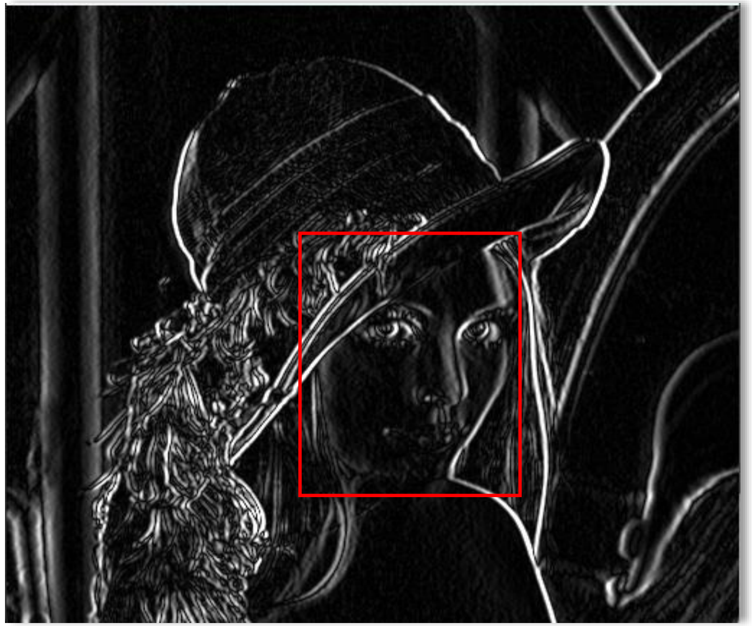
```
Mat calc_gradient_magnitude_orientation(Mat& img_x, Mat& img_y, int k) {
    Mat mag = Mat::zeros(img_x.rows, img_x.cols, CV_32F);
    Mat orient = Mat::zeros(img_x.rows, img_x.cols, CV_32F);

    for (int x = 0; x < img_x.cols; ++x) {
        for (int y = 0; y < img_y.rows; ++y) {
            mag.at<float>(y, x) = sqrt(img_x.at<float>(y, x) * img_x.at<float>(y, x) + img_y.at<float>(y, x) * img_y.at<float>(y, x));
            float a = 10*atan2(img_y.at<float>(y, x), img_x.at<float>(y, x));
            if (a < 0) a = -a;
            orient.at<float>(y, x) =a;
        }
    }
    if (k == 1) return mag;
    else return orient;
}
```

Canny Edge Detector

Step 2.
Sobel 연산자를 이용하여 **Gradient**를 구한다.

Gradient **magnitude** : $\|\nabla n_\sigma * \mathbf{I}\|$

Gradient **orientation** : $\hat{n} = \frac{\nabla n_\sigma * \mathbf{I}}{\|\nabla n_\sigma * \mathbf{I}\|}$



Sobel_x_conv

Sobel_y_conv

Sobel_combined
w = 0.5

Canny Edge Detector

Step 2.
Sobel 연산자를 이용하여 **Gradient**를 구한다.

Gradient **magnitude** : $\|\nabla \boldsymbol{n}_{\boldsymbol{\sigma}} * \mathbf{I}\|$

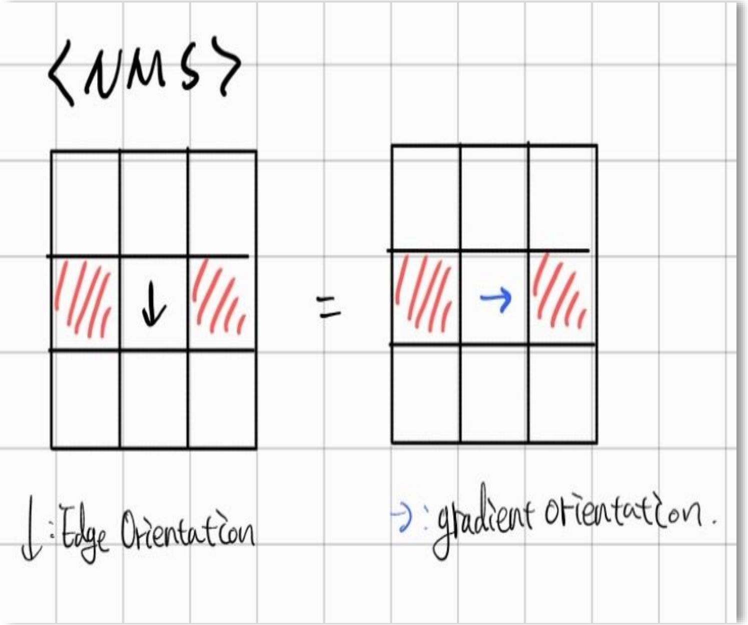
Gradient **orientation** : $\widehat{\boldsymbol{n}} = \frac{\nabla \boldsymbol{n}_{\boldsymbol{\sigma}} * \mathbf{I}}{\|\nabla \boldsymbol{n}_{\boldsymbol{\sigma}} * \mathbf{I}\|}$

Gradient magnitude

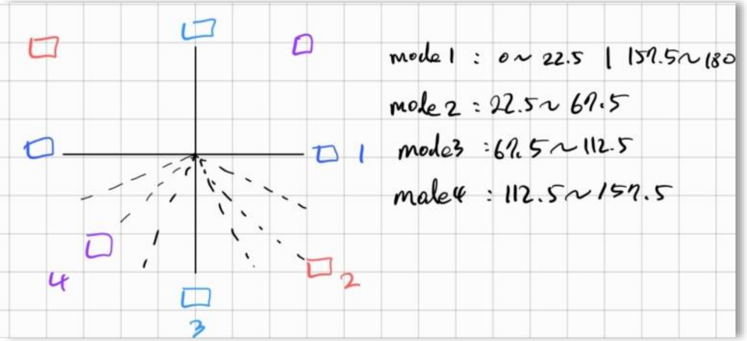
Gradient orientation

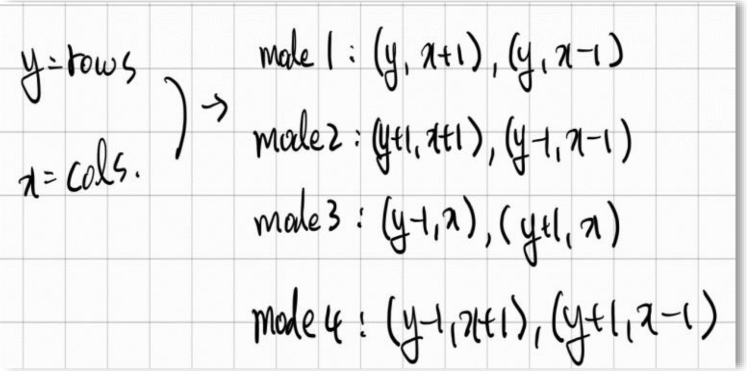
Canny Edge Detector

Step 3.
Non-maximum suppression
두꺼운 에지 제거



Criteria : Gradient orientation





1. Atan2 -> -π ~ π

2. 각도의 절댓값 저장(0 ~ 180°)

3. 각도에 따른 모드 설정

4. 모드에 따른 주변 픽셀 고려 후 억제

Canny Edge Detector

Step 3.

Non-maximum suppression

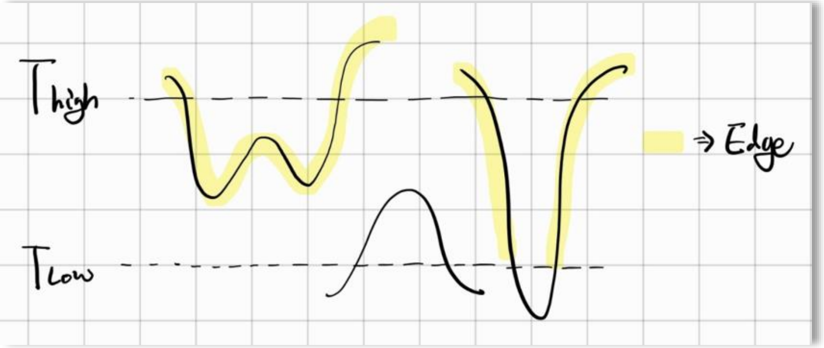
두꺼운 에지 제거

Img_NMS

```
Mat NMS(Mat& mag, Mat& orient) {
  Mat img_NMS(mag.rows, mag.cols, CV_32F);
  Mat mag_p;
  int d = 1;
  int mode = 0;
  copyMakeBorder(mag, mag_p, d, d, d, d, BORDER_CONSTANT, 0);

  for (int x = d; x < mag_p.cols - d; ++x) {
    for (int y = d; y < mag_p.rows - d; ++y) {
      float value = orient.at<float>(y-d, x-d);

      if ((0 <= value && value < 22.5) || (157.5 <= value && value < 180))  mode = 1;
      else if (22.5 <= value && value < 67.5) mode = 2;
      else if (67.5 <= value && value < 112.5) mode = 3;
      else mode = 4;

      switch (mode) {
      case 1:
        if ((mag_p.at<float>(y, x) < mag_p.at<float>(y, x - 1)) || (mag_p.at<float>(y, x) < mag_p.at<float>(y, x + 1))) img_NMS.at<float>(y - d, x - d) = 0;
        else img_NMS.at<float>(y - d, x - d) = mag_p.at<float>(y, x);
        break;
      case 2:
        if ((mag_p.at<float>(y, x) < mag_p.at<float>(y + 1, x + 1)) || (mag_p.at<float>(y, x) < mag_p.at<float>(y - 1, x - 1))) img_NMS.at<float>(y - d, x - d) = 0;
        else img_NMS.at<float>(y - d, x - d) = mag_p.at<float>(y, x);
        break;
      case 3:
        if ((mag_p.at<float>(y, x) < mag_p.at<float>(y - 1, x)) || (mag_p.at<float>(y, x) < mag_p.at<float>(y + 1, x))) img_NMS.at<float>(y - d, x - d) = 0;
        else img_NMS.at<float>(y - d, x - d) = mag_p.at<float>(y, x);
        break;
      case 4:
        if ((mag_p.at<float>(y, x) < mag_p.at<float>(y - 1, x + 1)) || (mag_p.at<float>(y, x) < mag_p.at<float>(y + 1, x - 1))) img_NMS.at<float>(y - d, x - d) = 0;
        else img_NMS.at<float>(y - d, x - d) = mag_p.at<float>(y, x);
        break;
      }
    }
  }

  return img_NMS;
}
```

Canny Edge Detector

Step 4.
Hysteresis thresholding
최종 에지 선정 (T_{high}는 T_{low}의 2~3배 설정)



T_{Low} < $\|\nabla I(x, y)\|$ < T_{high}

$\|\nabla I(x, y)\| > T_{high}$: Edge
$\|\nabla I(x, y)\| < T_{Low}$: not Edge

```
Mat Hysteresis_Threshold(Mat& img_NMS, float lowThreshold, float highThreshold) {
  Mat img_H = Mat::zeros(img_NMS.rows, img_NMS.cols, CV_8U); int d = 1;
  Mat img_NMS_p; copyMakeBorder(img_NMS, img_NMS_p, d, d, d, d, BORDER_CONSTANT, 0);
  int flag = 0;

  for (int x = d; x < img_NMS_p.cols -d; ++x) {
    for (int y = d; y < img_NMS_p.rows - d ; ++y) {
      if (img_NMS_p.at<float>(y, x) > highThreshold) { img_H.at<uchar>(y - d, x - d) = 255; }
      else if (img_NMS_p.at<float>(y, x) >= lowThreshold) {
        for (int m = -1; m <= 1; ++m) {
          for (int n = -1; n <= 1; ++n) {
            if (img_NMS_p.at<float>(y + m, x + n) >= highThreshold) {
              flag = true;
              break;
            }
          }
          if (flag) break;
        }
        img_H.at<uchar>(y - d, x - d) = (flag) ? 255 : 0;
      }

      else {img_H.at<uchar>(y - d, x - d) = 0;}
      flag = 0;

    }
  }
  return img_H;
}
```

Canny Edge Detector

Step 4.
Hysteresis thresholding
최종 에지 선정

lowThreshold = 30
HighThreshold = 60

lowThreshold = 30
HighThreshold = 90

lowThreshold = 50
HighThreshold = 150

감사합니다.