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(a) Source codes:

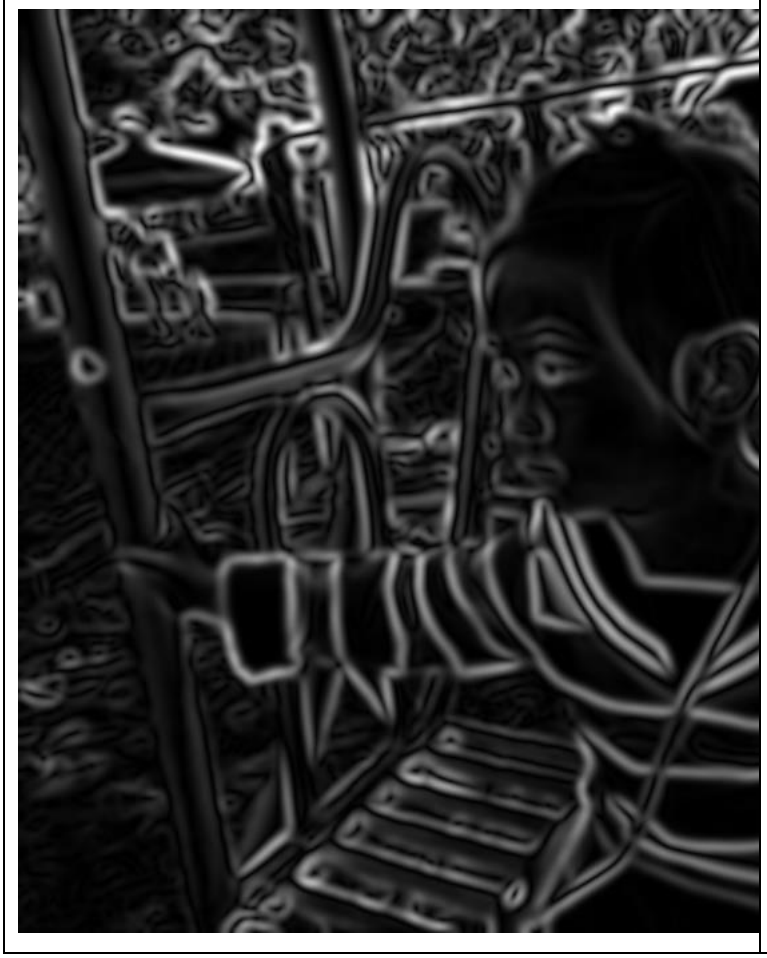
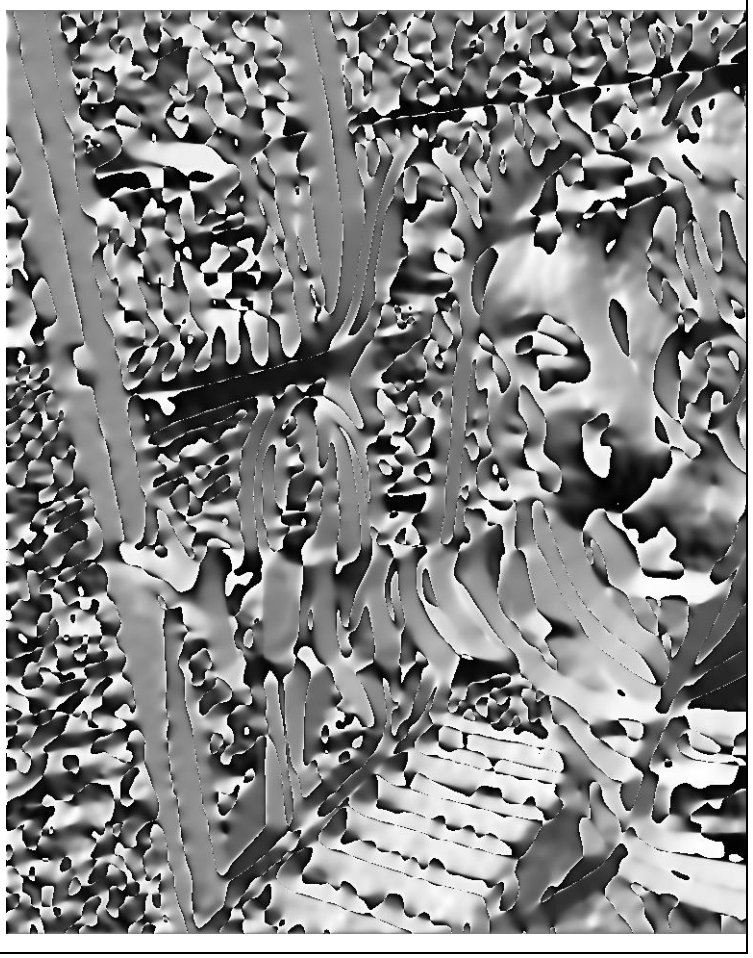
```
import numpy as np
import cv2
import matplotlib.pyplot as plt
from PIL import Image
from random import randint
import math
import random
from scipy import ndimage



def gaussian_kernel(size, sigma):
    size = int(size) // 2
    x, y = np.mgrid[-size:size+1, -size:size+1]
    normal = 1 / (2.0 * np.pi * sigma**2)
    g = np.exp(-((x**2 + y**2) / (2.0*sigma**2))) * normal
    return g



def sobel_filters(img):
    # kernel
    Kx = np.array([[-1, 0, 1], [-2, 0, 2], [-1, 0, 1]], np.float32)
    Ky = np.array([[1, 2, 1], [0, 0, 0], [-1, -2, -1]], np.float32)

    Ix = ndimage.filters.convolve(img, Kx)
    Iy = ndimage.filters.convolve(img, Ky)

    G = np.hypot(Ix, Iy)
    G = G / G.max()
    theta = np.arctan2(Iy, Ix)
    return (G, theta)



def non_max_suppression(img, D):
    M, N = img.shape
    Z = np.zeros((M, N), dtype=np.float32)
    angle = D * 180. / np.pi
    angle[angle < 0] += 180

    for i in range(1, M-1):
        for j in range(1, N-1):
            try:
                q = 255
                r = 255
```

```
            # angle 0
            if (0 <= angle[i, j] < 22.5) or (157.5 <= angle[i, j] <= 180):
                q = img[i, j+1]
                r = img[i, j-1]
            # angle 45
            elif (22.5 <= angle[i, j] < 67.5):
                q = img[i+1, j-1]
                r = img[i-1, j+1]
            # angle 90
            elif (67.5 <= angle[i, j] < 112.5):
                q = img[i+1, j]
                r = img[i-1, j]
            # angle 135
            elif (112.5 <= angle[i, j] < 157.5):
                q = img[i-1, j-1]
                r = img[i+1, j+1]

            if (img[i, j] >= q) and (img[i, j] >= r):
                Z[i, j] = img[i, j]
            else:
                Z[i, j] = 0

        except IndexError as e:
            pass

    return Z


def threshold(img):

    highThreshold = 0.1
    lowThreshold = 0.04

    M, N = img.shape
    res = np.zeros((M, N), dtype=np.float32)

    weak = np.float32(0.5)
    strong = np.float32(1)

    strong_i, strong_j = np.where(img >= highThreshold)
    zeros_i, zeros_j = np.where(img < lowThreshold)

    weak_i, weak_j = np.where((img <= highThreshold) & (img >= lowThreshold))
```

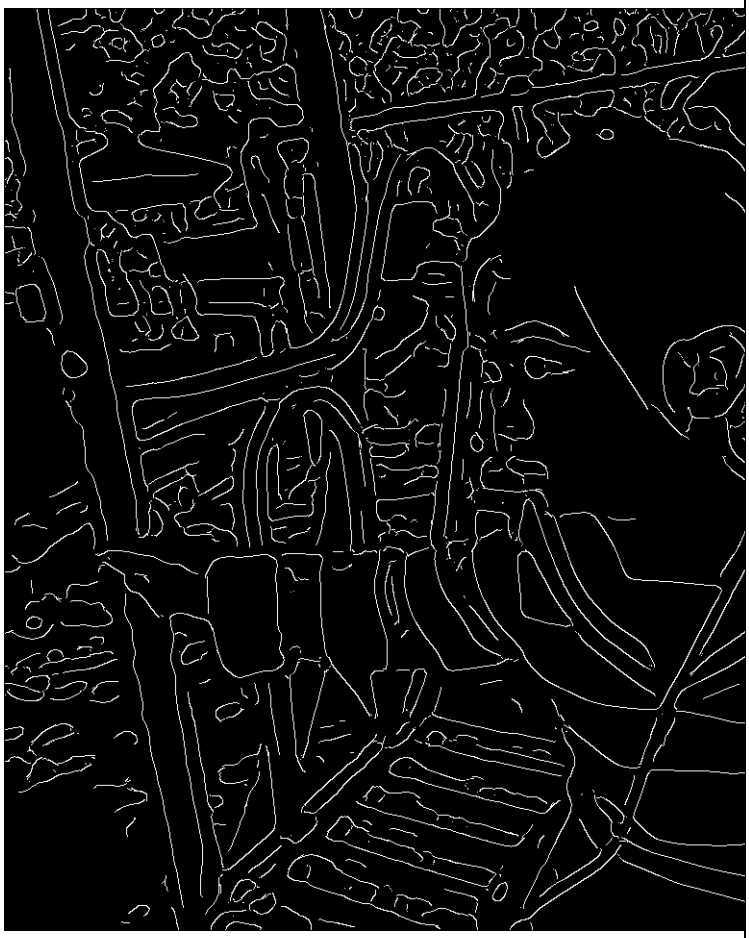
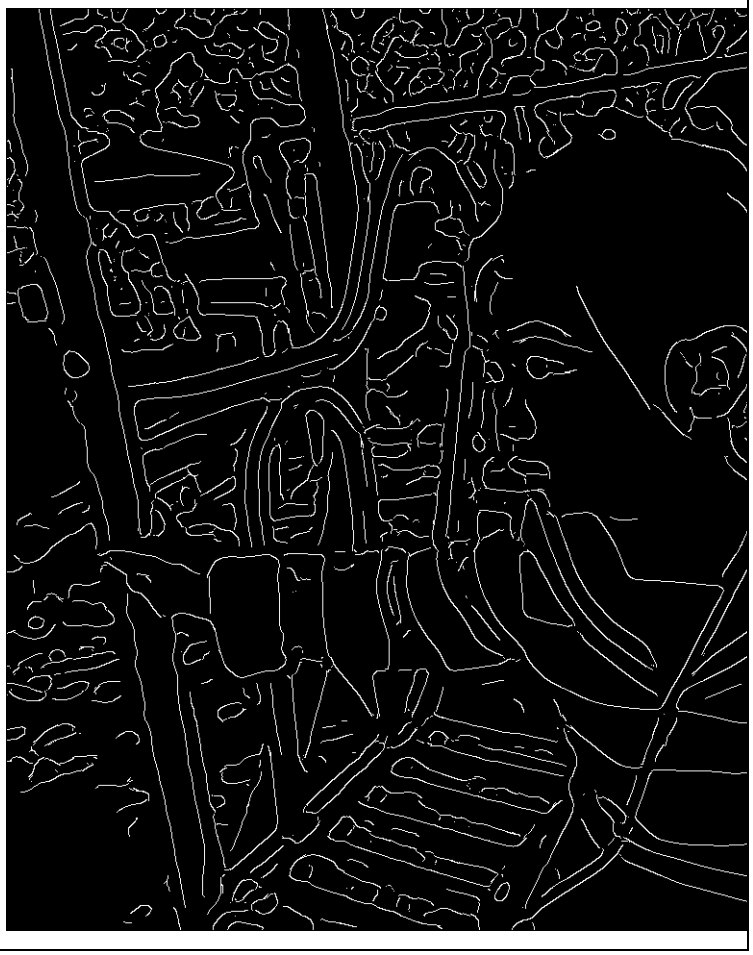
```
    img_weak = np.zeros((img.shape[0], img.shape[1]), dtype=np.float32)
    img_strong = np.zeros((img.shape[0], img.shape[1]), dtype=np.float32)
    img_weak[weak_i, weak_j] = weak
    img_strong[strong_i, strong_j] = strong

    res[strong_i, strong_j] = strong
    res[weak_i, weak_j] = weak

    return (res, img_weak, img_strong)


def hysteresis(img, weak, strong=1):
    M, N = img.shape
    for i in range(1, M-1):
        for j in range(1, N-1):
            if (img[i, j] == weak):
                try:
                    if ((img[i+1, j-1] == strong) or (img[i+1, j] == strong) or (img[i+1, j+1] == strong)
                        or (img[i, j-1] == strong) or (img[i, j+1] == strong)
                            or (img[i-1, j-1] == strong) or (img[i-1, j] == strong) or (img[i-1, j+1] == strong)):
                        img[i, j] = strong
                    else:
                        img[i, j] = 0
                except IndexError as e:
                    pass
    return img


if __name__ == "__main__":

    # 位啥要-1
    image = cv2.imread('Kid at playground.tif', -1)
    normalized_image = image/255

    # guassion LPF
    # 位啥 size 是 31？
    GLP = gaussian_kernel(31, sigma=5)
    img_glp = cv2.filter2D(normalized_image, -1, GLP)
    cv2.imshow("Gaussian", img_glp)

    # sobel gradient calculation
    magnitude, theta = sobel_filters(img_glp)
    cv2.imshow("magnitude", magnitude)
    cv2.imshow("angle", theta)
    PILimage = magnitude*255
```

```
PILimage = Image.fromarray(PILimage.astype(np.uint8))
PILimage.save("img/magnitude.png", dpi=(200, 200))
PILimage = (theta+np.pi/2)/np.pi*255
PILimage = Image.fromarray(PILimage.astype(np.uint8))
PILimage.save("img/theta.png", dpi=(200, 200))

# nunmaxima suppression
nun_sup = non_max_suppression(magnitude, theta)
cv2.imshow("suppression", nun_sup)
PILimage = nun_sup*255
PILimage = Image.fromarray(PILimage.astype(np.uint8))
PILimage.save("img/non_max_suppression.png", dpi=(200, 200))

# hysteresis thresholding
final_img, gNL, gNH = threshold(nun_sup)
final = hysteresis(final_img, 0.5, 1)
cv2.imshow("final_img", final_img)
cv2.imshow("gNL", gNL)
cv2.imshow("gNH", gNH)
cv2.imshow("final", final)
cv2.waitKey(0)
PILimage = final_img*255
PILimage = Image.fromarray(PILimage.astype(np.uint8))
PILimage.save("img/final_img.png", dpi=(200, 200))
PILimage = gNL*255
PILimage = Image.fromarray(PILimage.astype(np.uint8))
PILimage.save("img/gNL.png", dpi=(200, 200))
PILimage = gNH*255
PILimage = Image.fromarray(PILimage.astype(np.uint8))
PILimage.save("img/gNH.png", dpi=(200, 200))
```

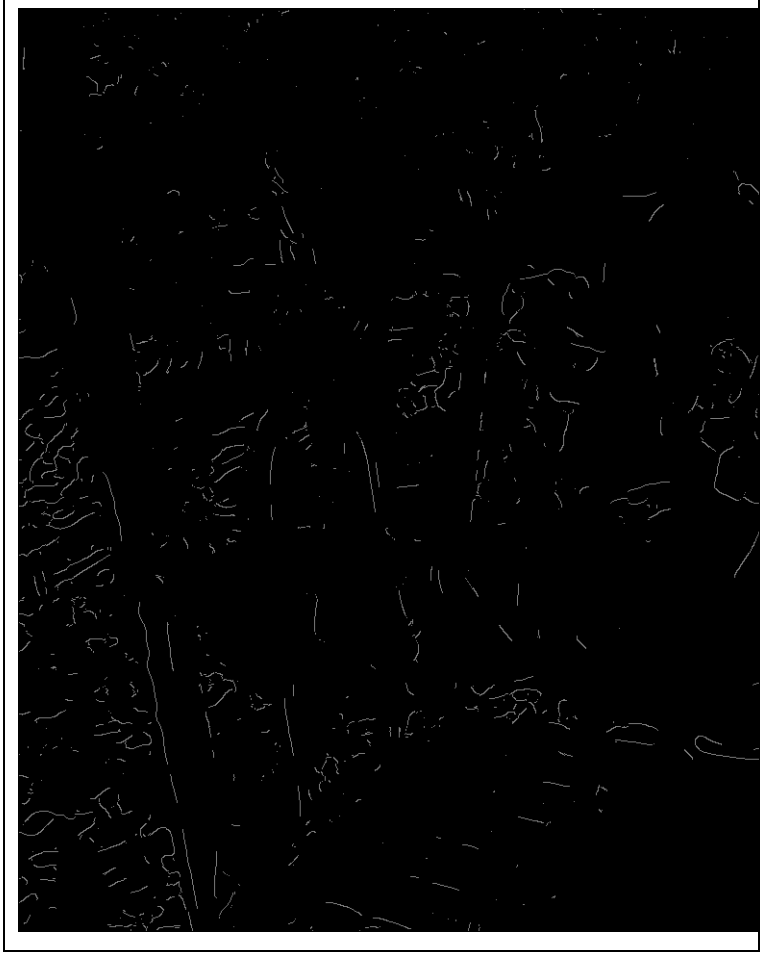
(b) Plot images of the gradient magnitude and gradient angle:

magnitude	Angle
	

(c) Plot nonmaxima suppressed image g_N (x,y) as well as images of g_{NL}(x,y) and g_{NH}(x,y):

g_N (x,y)	g_{NL}(x,y)
	

$g_{NH}(x,y)$



(d) Plot final edge map e(x,y):