

## EE 569: Homework #2

Issued: 1/20/2019      Due: 11:59PM, 2/12/2019

### General Instructions:

1. Read *Homework Guidelines* and *MATLAB Function Guidelines* for the information about homework programming, write-up and submission. If you make any assumptions about a problem, please clearly state them in your report.
2. You need to understand the USC policy on academic integrity and penalties for cheating and plagiarism. These rules will be strictly enforced.

### Problem 1: Edge Detection (50 %)

#### a) Sobel Edge Detector (Basic: 10%)

Implement the Sobel edge detector and apply to *Tiger* and *Pig* images as shown in Fig. 1 (a) and (b). Note that you need to convert RGB images to grey-level image first. Include the following in your results:

- Normalize the x-gradient and the y-gradient values to 0-255 and show the results.
- Tune the thresholds (in terms of percentage) to obtain your best edge map. An edge map is a binary image whose pixel values are either 0 (edge) or 255 (background)

#### b) Canny Edge Detector (Basic: 10%)

The Canny edge detector is an edge detection technique utilizing image's intensity gradients and non-maximum suppression with double thresholding. In this part, apply the Canny edge detector [1] to both *Tiger* and *Pig* images. You are allowed to use any online source code such as the Canny edge detector in the MATLAB image processing toolbox or the OpenCV (i.e. Open Source Computer Vision Library). Generate edge maps by trying different low and high thresholds. Answer the following questions:

1. Explain Non-maximum suppression in Canny edge detector in your own words.
2. How are high and low threshold values used in Canny edge detector?



Figure 1: *Tiger* and *Pig* images

#### c) Structured Edge (Advanced: 15%)

Apply the Structured Edge (SE) detector [2] to extract edge segments from a color image with online source codes (released MATLAB toolbox: <https://github.com/pdollar/edges>). Exemplary edge maps generated by the SE method for the *House* image are shown in Figure 2. You can apply the SE detector to

the RGB image directly without converting it into a grayscale image. Also, the SE detector will generate a probability edge map. To obtain a binary edge map, you need to binarize the probability edge map with a threshold.

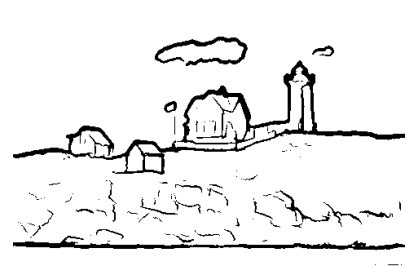
1. Please digest the SE detection algorithm. Summarize it with a flow chart and explain it in your own words (no more than 1 page, including both the flow chart and your explanation).
2. The Random Forest (RF) classifier is used in the SE detector. The RF classifier consists of multiple decision trees and integrate the results of these decision trees into one final probability function. Explain the process of decision tree construction and the principle of the RF classifier.
3. Apply the SE detector to *Tiger* and *Pig* images. State the chosen parameters clearly and justify your selection. Compare and comment on the visual results of the Canny detector and the SE detector.



House

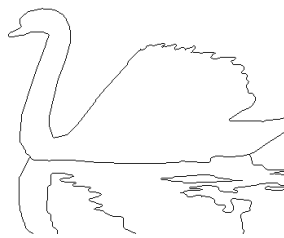


Probability edge map

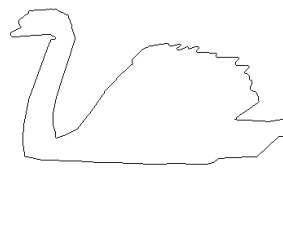
Binary edge map (with  $p > 0.2$ )

**Figure 2: The *House* image and its probability and binary edge maps obtained by the SE detector**

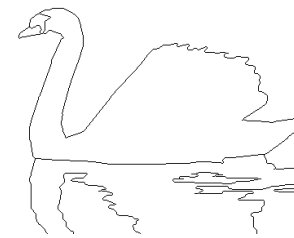
**d) Performance Evaluation (Advanced: 15%)**



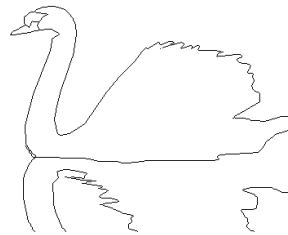
Ground Truth 1



Ground Truth 2



Ground Truth 3



Ground Truth 4



Ground Truth 5

**Figure 3: Five ground truth edge maps for the *Goose* image**

Perform quantitative comparison between different edge maps obtained by different edge detectors. The ultimate goal of edge detection is to enable the machine to generate contours of priority to human being. For this reason, we need the edge map provided by human (called the ground truth) to evaluate the quality

of a machine-generated edge map. However, different people may have different opinions about important edge in an image. To handle the opinion diversity, it is typical to take the mean of a certain performance measure with respect to each ground truth, e.g. the mean precision, the mean recall, etc. Figure 3 shows 5 ground truth edge maps for the *Goose* image from the Berkeley Segmentation Dataset and Benchmarks 500 (BSDS 500) [3]. To evaluate the performance of an edge map, we need to identify the error. All pixels in an edge map belong to one of the following four classes:

- (1) True positive: Edge pixels in the edge map coincide with edge pixels in the ground truth. These are edge pixels the algorithm successfully identifies.
- (2) True negative: Non-edge pixels in the edge map coincide with non-edge pixels in the ground truth. These are non-edge pixels the algorithm successfully identifies.
- (3) False positive: Edge pixels in the edge map correspond to the non-edge pixels in the ground truth. These are fake edge pixels the algorithm wrongly identifies.
- (4) False negative: Non-edge pixels in the edge map correspond to the true edge pixels in the ground truth. These are edge pixels the algorithm misses.

Clearly, pixels in (1) and (2) are correct ones while those in (3) and (4) are error pixels of two different types to be evaluated. The performance of an edge detection algorithm can be measured using the F measure, which is a function of the precision and the recall.

$$\begin{aligned}
 \text{Precision : } P &= \frac{\# \text{True Positive}}{\# \text{True Positive} + \# \text{False Positive}} \\
 \text{Recall : } R &= \frac{\# \text{True Positive}}{\# \text{True Positive} + \# \text{False Negative}} \\
 F &= 2 \cdot \frac{P \cdot R}{P + R}
 \end{aligned} \tag{1}$$

One can make the precision higher by decreasing the threshold in deriving the binary edge map. However, this will result in a lower recall. Generally, we need to consider both precision and recall at the same time and a metric called the F measure is developed for this purpose. A higher F measure implies a better edge detector.

For the ground truth edge maps of *Tiger* and *Pig* images, evaluate the quality of edge maps obtained in Parts (a)-(c) with the following:

1. Calculate the precision and recall for each ground truth (saved in .mat format) separately using the function provided by the SE software package and, then, compute the mean precision and the mean recall. Finally, calculate the F measure for each generated edge map based on the mean precision and the mean recall. Please use a table to show the precision and recall for each ground truth, their means and the final F measure. Comment on the performance of different edge detectors (i.e. their pros and cons.)
2. The F measure is image dependent. Which image is easier to get high F measure - *Tiger* or *Pig*? Please provide an intuitive explanation to your answer.
3. Discuss the rationale behind the F measure definition. Is it possible to get a high F measure if precision is significantly higher than recall, or vice versa? If the sum of precision and recall is a constant, show that the F measure reaches the maximum when precision is equal to recall.

## Problem 2: Digital Half-toning (50%)

### a) Dithering (Basic: 15%)

Fig. 4 is grayscale image. Implement the following methods to convert it to half-toned images. In the following discussion,  $F(i,j)$  and  $G(i,j)$  denote the pixel of the input and the output images at position  $(i,j)$ , respectively. Compare the results obtained by these algorithms in your report.



**Figure 4: Golden Gate Bridge**

#### 1. Random thresholding

In order to break the monotones in the result from fixed thresholding, we may use a ‘random’ threshold. The algorithm can be described as:

- For each pixel, generate a random number in the range  $0 \sim 255$ , so called  $rand(i,j)$
- Compare the pixel value with  $rand(i,j)$ . If it is greater, then map it to 255; otherwise, map it to 0, i.e.

$$G(i,j) = \begin{cases} 0 & \text{if } 0 \leq F(i,j) < rand(i,j) \\ 255 & \text{if } rand(i,j) \leq F(i,j) < 256 \end{cases}$$

A choice of random threshold could be uniformly distributed random variable. Check your coding language documentation for proper random variable generator.

#### 2. Dithering Matrix

Dithering parameters are specified by an index matrix. The values in an index matrix indicate how likely a dot will be turned on. For example, an index matrix is given by

$$I_2(i,j) = \begin{bmatrix} 1 & 2 \\ 3 & 0 \end{bmatrix}$$

where 0 indicates the pixel most likely to be turned on, and 3 is the least likely one. This index matrix is a special case of a family of dithering matrices first introduced by Bayer [4]. The Bayer index matrices are defined recursively using the formula:

$$I_{2n}(i,j) = \begin{bmatrix} 4 \times I_n(i,j) + 1 & 4 \times I_n(i,j) + 2 \\ 4 \times I_n(i,j) + 3 & 4 \times I_n(i,j) \end{bmatrix}$$

The index matrix can then be transformed into a threshold matrix  $T$  for an input gray-level image with normalized pixel values (i.e. with its dynamic range between 0 and 255) by the following formula:

$$T(x,y) = \frac{I(x,y) + 0.5}{N^2} \times 255$$

where  $N^2$  denotes the number of pixels in the matrix. Since the image is usually much larger than the threshold matrix, the matrix is repeated periodically across the full image. This is done by using the following formula:

$$G(i,j) = \begin{cases} 0 & \text{if } 0 \leq F(i,j) \leq T(i \bmod N, j \bmod N) \\ 255 & T(i \bmod N, j \bmod N) < F(i,j) < 256 \end{cases}$$

Please create  $I_2$ ,  $I_8$ ,  $I_{32}$  thresholding matrices and apply them to halftone Fig. 4. Compare your results.

### b) Error Diffusion (Basic: 15%)

Convert the 8-bit Fig.4 image to a half-toned one using the error diffusion method. Show the outputs of the following three variations and discuss these obtained results. Compare these results with dithering matrix. Which method do you prefer? Why?

1. Floyd-Steinberg's error diffusion with the serpentine scanning, where the error diffusion matrix is:

$$\frac{1}{16} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 7 \\ 3 & 5 & 1 \end{bmatrix}$$

2. Error diffusion proposed by Jarvis, Judice, and Ninke (JJN), where the error diffusion matrix is:

$$\frac{1}{48} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 7 & 5 \\ 3 & 5 & 7 & 5 & 3 \\ 1 & 3 & 5 & 3 & 1 \end{bmatrix}$$

3. Error diffusion proposed by Stucki, where the error diffusion matrix is:

$$\frac{1}{42} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 8 & 4 \\ 2 & 4 & 8 & 4 & 2 \\ 1 & 2 & 4 & 2 & 1 \end{bmatrix}$$

Describe your own idea to get better results. There is no need to implement it if you do not have time. However, please explain why your proposed method will lead to better results.

**c) Color Halftoning with Error Diffusion (Advanced: 20%)**



**Figure 5: The bird image<sup>[8]</sup>**

**1. Separable Error Diffusion**

One simple idea to achieve color halftoning is to separate an image into CMY three channels and apply the Floyd-Steinberg error diffusion algorithm to quantize each channel separately. Then, you will have one of the following 8 colors, which correspond to the 8 vertices of the CMY cube at each pixel:

$$\begin{aligned} W &= (0,0,0), Y = (0,0,1), C = (0,1,0), M = (1,0,0), \\ G &= (0,1,1), R = (1,0,1), B = (1,1,0), K = (1,1,1) \end{aligned}$$

Note that (W, K), (Y, B), (C, R), (M, G) are complementary color pairs. Please show and discuss the result of the half-toned color bird image. What is the main shortcoming of this approach?

**2. MBVQ-based Error diffusion**

Shaked et al. [5] proposed a new error diffusion method, which can overcome the shortcoming of the separable error diffusion method. Please read [5] carefully, and answer the following questions:

- 1) Describe the key ideas on which the MBVQ-based Error diffusion method is established and give reasons why this method can overcome the shortcoming of the separable error diffusion method.
- 2) Implement the algorithm using a standard error diffusion process (e.g. the FS error diffusion) and apply it to Fig. 5. Compare the output with that obtained by the separable error diffusion method.

**Appendix:****Problem 1: Edge detection**

Tiger.raw	481x321x3	24-bit	color(RGB)
Pig.raw	481x321x3	24-bit	color(RGB)
Tiger.jpg	481x321x3	24-bit	color(RGB)
Pig.jpg	481x321x3	24-bit	color(RGB)
Tiger.mat	(containing 5 ground truth images)		
Pig.mat	(containing 5 ground truth images)		
House.png	481x321x3	24-bit	color(RGB)
House_binary.png	481x321		logical
House_probmap.png	481x321	8-bit	gray

**Problem 2: Digital Half-toning**

bridge.raw	600x400	8-bit	gray
bird.raw	500x375x3	24-bit	color(RGB)

**Reference Images**

Images in this homework are from the BSDS 500 [3], the USC-SIPI image database [6], the Google images [7] or the ImageNet dataset [8].

**References**

- [1] J. Canny, "A computational approach to edge detection," *IEEE Transactions on pattern analysis and machine intelligence*, no. 6, pp. 679–698, 1986.
- [2] P. Dollár and C. L. Zitnick, "Structured forests for fast edge detection," in *Proceedings of the IEEE International Conference on Computer Vision*, 2013, pp. 1841–1848.
- [3] P. Arbelaez, M. Maire, C. Fowlkes, and J. Malik, "Contour detection and hierarchical image segmentation," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 33, no. 5, pp. 898–916, May 2011.
- [Online]. Available: <http://dx.doi.org/10.1109/TPAMI.2010.161>
- [4] B. E. Bayer, "An optimum method for two-level rendition of continuous-tone pictures," *SPIE MILESTONE SERIES MS*, vol. 154, pp. 139–143, 1999
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- [6] [Online] <http://sipi.usc.edu/database/>
- [7] [Online] <http://images.google.com/>
- [8] [Online] <http://www.image-net.org/>