Exam: Introduction to Image Processing (Solutions)
November 6, 2015 - 11:00 – 13:00

Student name:                      Student number:

- Put your name and student number on all of the papers you hand in.
- Explain your answers. Simple answers such as yes and 4 will not be given any credit.
- For the images shown, brighter gray values correspond to higher pixel values.
- Fill in the answers in the boxes provided. Dutch or English are both fine.
- You are not allowed to use any other materials but a pen. So no reader, slides, phone, etc.
- Hand over the exam with your answers when you leave. Show your student ID card.
- You are free to leave at any moment after 11:30.
- The total number of points is 50.
- Good luck!

**Question 1**: (3 points) Under what circumstances does aliasing occur?

When sampling an image with a frequency below Nyquist.

**Question 2**: (3 points) Explain (1) what image slicing is and (2) give an example when it is useful.

(1) It is an image remapping function that maps a range of values between two thresholds to the maximum value, and everything below the lowest threshold and above the highest threshold to zero. (2) It is useful to extract a mask for a specific range of gray values.
Figure 1: Original Lena image (left) with four remapped images (A-D) and possible remapping functions 1-8. (right).

**Question 3:** (4 points)
Figure 1 (left) has been processed with four different functions. The results A-D are shown in Figure 1 (right) with possible remapping functions. Indicate, for each figure, which function (1-8) has been applied.

<table>
<thead>
<tr>
<th>A: 1</th>
<th>B: 7</th>
<th>C: 8</th>
<th>D: 6</th>
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**Question 4**: (2+6 points) When not the full range of pixel values is used, one can apply at least two methods to achieve this: (1) windowing and (2) histogram equalization.

a. Which of these two methods is more robust against salt-and-pepper noise (extremely high and low values)? Motivate your answer.

   **Windowing**, as you can specify the start and end of the slope, thus ignoring any outliers.

b. Given the histogram in Figure 2, calculate the equalized histogram. Explain the steps taken to arrive at your final answer. You may draw the resulting histogram, or put it in table-form (with clearly x (bin) and y (count) axes indicated). You may use the last (blank) paper of this exam.

![Figure 2: Histogram with 7 bins.](image)

Result: [2 3 3 6 6 6 6]. You get one point for i, two for the cumulative histogram, one for g(x) and two for the result.
Question 5: (6 points) We would like to put the UU logo (Figure 3a) over the Lena image (Figure 1(left)), pixel value range from 0 to 255). The histogram of the logo is given in Figure 4, with values from 0 to 255. Assume that the dimensions (width and height) of both images are the same.

Explain how only the text, in black, can be put over the Lena image (see Figure 3b). So the Lena image shows everywhere, except for the locations where there is text in the UU logo. You are not allowed to use conditional (i.e., with if statements) processing steps. Describe the steps needed to obtain this composite image (use estimated numbers!).

Identify that the text is the fourth peak (1 point). Explain how to select the range using window slicing, explicitly mentioning the thresholds (2 points). Explain that this is a mask, and invert it (1 point). Multiply with the original image (1 point).

Question 6: (2+2 points)
(a) Mathematically, how is a white top hat filter defined?

\[ T(f) = f - \gamma(f) \]

(b) In which case is a white top hat filter particularly useful? Give an example.

When there are low-frequency patterns in the "background", e.g. when there is a gradient.

Question 7: (4 points) Name two computational measures (e.g., area) that can be used to separate circles from ellipses, and explain how we can distinguish between the two shapes (e.g., area for circles is larger than for ellipses).
Choose two: Elongation/Circularity/Roundness. Circles have lower elongation, higher circularity (1) and roundness (1).

**Question 8:** (4 points) Give the $3 \times 3$ structuring element (foreground and background) that can be used to detect vertical lines using a hit-or-miss transformation of a binary image. The origin is in the center.

<table>
<thead>
<tr>
<th>Foreground ($X_1$)</th>
<th>Background ($X_2$)</th>
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<tbody>
<tr>
<td>X</td>
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</tbody>
</table>
**Question 9:** (6 points) Given this image $f(x, y)$:

```
1 4 7
2 5 8
3 6 9
```

with the origin (0, 0) located in the center of the top-left pixel, compute $f(1.6, 1.3)$ using (1) nearest neighbor interpolation, and (2) linear interpolation. Motivate your answer.

1. $8$, round $1.6 \rightarrow 2$, round $1.3 \rightarrow 1$. Closest pixel is $(2, 1)$ so value $8$. (2) first interpolate between $5$ and $8$: $5 + (8 - 5) \times 0.6 = 6.8$, then interpolate between $6$ and $9$: $6 + (9 - 6) \times 0.6 = 7.8$. Then interpolate between these two: $6.8 + (7.8 - 6.8) \times 0.3 = 7.1$

**Question 10:** (5 points) Compute the opening using a $3 \times 3$ '+'-shaped structuring element of the image below. You don’t have to explain your answer.

First erosion:

```
1 1 1
1 1 1
```

Then dilation:

```
1 1 1
1 1 1
1 1 1
1 1 1
1 1 1
1 1 1
```
**Question 11:** (3 points) Given an original (left) and a processed (right) image:

Which of these kernels was used to obtain the processed image? Motivate your answer.

The resulting image is not blurred, ruling out kernels 1 and 4. Observe that large horizontal contrast (left side of the ball) results in zero values so this is not a horizontal edge detector. This rules out kernels 2 and 3. A change from light to dark (top side of the ball) leads to a positive value. This corresponds to the last kernel, kernel 6. A high value times 1 plus a low value times -1 give a positive number. For kernel 5, this is opposite, so this kernel was not used.

**That’s it!**