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Solutions for exam "Machine Vision" February 14, 2020

Question 1 (5 points)

The images below show a barcode which encodes the term 'machine vision' as well as a photo of the barcode. Unfortunately the barcode in the photo cannot be detected by a barcode reader. Which effect with respect to signal theory can be observed in this case? Explain why it is not possible to read the barcode from the photo.
How could this effect be avoided? Name two possible ways to take a better photo.

M A C H I N E V I S I O N

M A C H I N E V I S I O N

Solution

Moiré patterns are observed due to high frequences in the image/ low sample frequency. The sampling frequency (resolution of the image) is too low to display the finest lines/ the frequency of the lines in the barcode is to high to be perceived in the image.
Possible methods to get a better photo:

- larger resolution
- lens with larger focal length
- smaller distance to the barcode

Question 2 (8 points)

Implement the non-maxima suppression approach of the Canny edge detector as a MATLAB function. The function should take the following arguments

- two real-valued image matrices `dgdu, dgdv` that contain the partial derivatives in horizontal and vertical direction for all pixels of the image
- a pixel position `u, v` for which the non-maxima suppression should be applied. You can assume that the function is not applied to pixels at the boundary of the image.

The function should return either `0` if the pixel should be suppressed by the non-maxima suppression or `1` if the pixel should not be suppressed.

You might use a function called `relative` that takes a 2d vector `(x,y)` and returns a 2d vector from the set $\{(-1,-1),(-1,0),(-1,1),(0,1),(1,1),(1,0),(1,-1),(0,-1)\}$ that points to the neighboring pixel with the most similar direction as `(x,y)`, e.g. `relative(2.3,0.2)` yields $(1,0)$, `relative(-1.3,1.4)` yields $(-1,1)$, `relative(1,-20)` yields $(0,-1)$.

Add your solution below the following function header

```
function [ q ] = non_maxima_suppression (dgdu, dgdv, u, v)
```

Solution

```
function [ q ] = non_maxima_suppression (dgdu, dgdv, u, v)
   [du dv] = relative (dgdu(v,u),dgdv(v,u));
   len2 = dgdu(v,u)^2+dgdv(v,u)^2;
   len2a = dgdu(v+dv,u+du)^2+dgdv(v+dv,u+du)^2;
   len2b = dgdu(v-dv,u-du)^2+dgdv(v-dv,u-du)^2;
   q = (len2>len2a) && (len2>len2b);
end
```

Question 3 (7 points)

Consider the four points $\vec{x}_i$ given below. With RANSAC three lines l_1, l_2, and l_3 have been generated as possible candidate lines. Calculate the distances from each point to each candidate line and evaluate the number of outliers for each of the three candidates. Use an outlier threshold of $\theta = 1$. Which line fits best?

Remark: Note that the line equations are not normalized.

$$\vec{x}_1 = \begin{pmatrix} 2 \\ 0 \end{pmatrix}, \quad \vec{x}_2 = \begin{pmatrix} 0 \\ -0.5 \end{pmatrix}, \quad \vec{x}_3 = \begin{pmatrix} 7.5 \\ 0 \end{pmatrix}, \quad \vec{x}_4 = \begin{pmatrix} -3 \\ 0.5 \end{pmatrix}$$

$$l_1 : \left\langle \begin{pmatrix} -1 \\ 4 \end{pmatrix}, \vec{x} \right\rangle + 2 = 0$$

$$l_2 : \left\langle \begin{pmatrix} 1 \\ 3 \end{pmatrix}, \vec{x} \right\rangle + 1.5 = 0$$

$$l_3 : \left\langle \begin{pmatrix} 0 \\ 1 \end{pmatrix}, \vec{x} \right\rangle = 0$$

Solution

Calculate the distance from each point $\vec{x}_i$ to each line l_1, l_2, and l_3 by the formula $d = \frac{|\langle \vec{n}, \vec{x}_i \rangle + c|}{||\vec{n}||}$ and compare it with θ (or calculate d^2 and compare it with θ^2) .

	x_1	x_2	x_3	x_4	*outlier*
l_1	$0 \leq 1$	$0 \leq 1$	$5.5\frac{1}{\sqrt{17}} > 1$	$7\frac{1}{\sqrt{17}} > 1$	2
l_2	$3.5\frac{1}{\sqrt{10}} > 1$	$0 \leq 1$	$9\frac{1}{\sqrt{10}} > 1$	$0 < 1$	2
l_3	$0 \leq 1$	$0.5 \leq 1$	$0 \leq 1$	$0.5 \leq 1$	0

Line l_3 fits best.

Question 4 (4 points)

Explain why surfaces of colored objects appear differently if (a) they are seen outside in bright sunlight, and if (b) they are seen inside of a building without windows that is illuminated only by white fluorescent tubes.

Solution

The perceived color of a surface depends on the reflectance properties of the surface and on the illumination of the surface. The spectra of sunlight and artificial light sources is different, even if both appear as white light. Together with the reflectance properties of the object surface that filters out light of some wavelengths more than light of other wavelengths, the spectrum of the reflected light is different and therefore appears differently.

Question 5 (5+2 points)

Develop a level set based segmentation method that mimics the region growing algorithm on graylevel images. Pixels should be added to the foreground segment if their gray value does not deviate more from the average gray value of the foreground segment than a given threshold $\theta > 0$.

(a) Provide an evolution dynamics for the boundary pixels, i.e. specify $\frac{\partial \vec{x}}{\partial t}$. You might use the variables g (gray value of pixel at position $\vec{x}$), $\bar{g}$ (average gray value in foreground segment), θ (threshold), ϕ (level set function), and $\varepsilon > 0$ (step width of evolution step).

(b) Provide the initial signed distance function if we want to start the evolution with a seed pixel at position $\vec{x}_0$.

Solution

(a) The idea is that the segment should expand if $|g - \bar{g}| < \theta$ at a boundary pixel while otherwise the boundary should not change (or even shrink). $\frac{\nabla \phi}{||\nabla \phi||}$ provides a vector that points to the outside. Hence, we obtain

$$\frac{\partial \vec{x}}{\partial t} = \varepsilon \cdot (\theta - |g - \bar{g}|) \cdot \frac{\nabla \phi}{||\nabla \phi||}$$

(with shrinking) or

$$\frac{\partial \vec{x}}{\partial t} = \varepsilon \cdot \max\{\theta - |g - \bar{g}|, 0\} \cdot \frac{\nabla \phi}{||\nabla \phi||}$$

(without shrinking) or

$$\frac{\partial \vec{x}}{\partial t} = \begin{cases} \varepsilon \cdot \frac{\nabla \phi}{||\nabla \phi||} & \text{if } |g - \bar{g}| < \theta \\ 0 & \text{otherwise} \end{cases}$$

(b) The initial segment should contain only pixel $\vec{x}_0$. We obtain

$$\phi(\vec{x}, 0) = ||\vec{x} - \vec{x}_0|| - \frac{1}{2}$$

Question 6 (6+1 points)

Assume a camera with thin lens. The lens has a focal length of $f_{lens} = 5$ mm. The diameter of the aperture is $D = 10$ mm and the tolerance diameter for blur on the image plane is $\epsilon = 0.01$ mm. Assume we adjust the camera in such a way that objects at a distance of 5005 mm are mapped perfectly sharp to the image plane.

(a) Calculate the hyperfocal distance d_h of the camera, the nearest object distance g_{near} at which objects are mapped to an area on the image plane that has a diameter of at most ϵ, and the largest object distance g_{far} at which objects are mapped to an area on the image plane that has a diameter of at most ϵ.

(b) Does the depth of field increase or decrease if we increase the diameter of the aperture D? (No explanation necessary)

Solution

(a) The hyperfocal distance is defined as

$$d_h = \frac{D f_{lens}}{\epsilon} = \frac{10\ mm \cdot 5\ mm}{0.01\ mm} = 5000\ mm$$

The nearest object distance is

$$g_{near} = \frac{g d_h}{d_h + (g - f_{lens})} = \frac{5005\ mm \cdot 5000\ mm}{5000\ mm + 5000\ mm} = 2502.5\ mm$$

Since $g = d_h + f_{lens}$, the largest distance of objects g_{far} is infinity.

(b) The depth of field decreases with increasing D.

Question 7 (9 points)

A classification problem is solved to distinguish between four different object classes A, B, C, and D. The patterns are two-dimensional. For this reason, four classifiers were trained using the one-versus-the-rest approach as follows:

classifier	class	linear classifier
c_1	A	$x_1 - 3 > 0$
c_2	B	$2x_2 - x_1 - 2 > 0$
c_3	C	$-x_2 - 2 > 0$
c_4	D	$-3x_2 - x_1 - 3 > 0$

Add the decision boundaries of the four classifiers to the pattern space below. Label each area of the pattern space with the class (A, B, C, and D) which is predicted by the ensemble classifier. If the ensemble classifier is undecided for an area, list all the classes for which the ensemble classifier has at least one vote. Mark areas without any vote with the letter 'N'.

Draw carefully! In case you want to revise your solution, cross out Figure 1 and use Figure 2 instead.

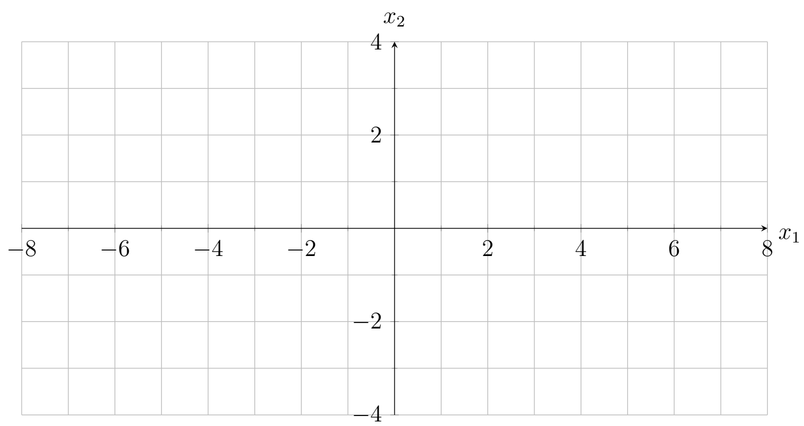


Figure 1: Enter your solution here.

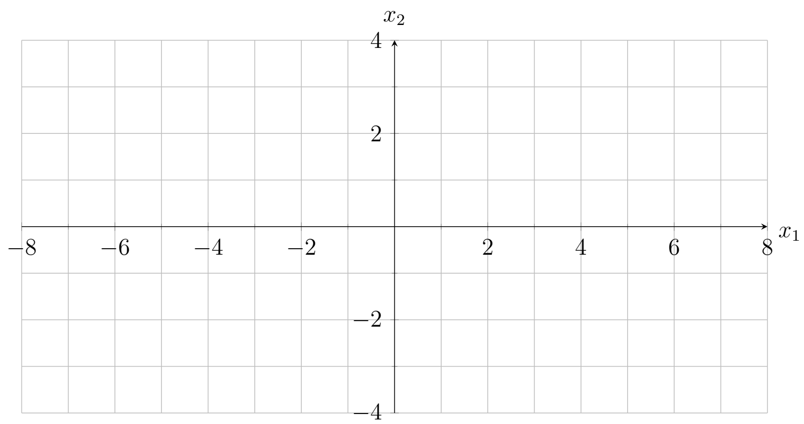
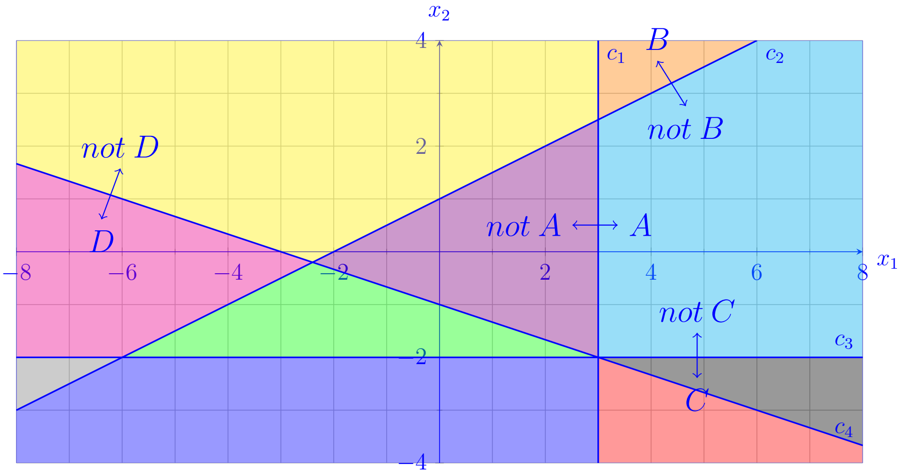


Figure 2: Spare image just in case you need it (e.g. if you want to revise your solution).

Solution



- cyan: A
- yellow: B
- green: D
- orange: A, B
- gray: A, C
- magenta: B, D
- blue: C, D
- red: A, C, D
- light gray: B, C, D
- violet: none

Question 8 (6+2 points)

Assume a convolutional neural network that is described in the table below.

layer	size (width×height×channels)	activation function	size of convolution kernel
1. input layer	$800 \times 600 \times 3$	-	-
2. convolutional layer	$800 \times 600 \times 48$	tanh	21×21
3. convolutional layer	$800 \times 600 \times 128$	tanh	11×11
4. convolutional layer	$800 \times 600 \times 256$	tanh	5×5
5. convolutional layer	$800 \times 600 \times 256$	tanh	1×1
6. fully connected layer	$100 \times 1 \times 1$	tanh	-
7. fully connected layer	$30 \times 1 \times 1$	softmax	-

(a) Calculate from which area of the input image the perceptrons at position $u = 400$, $v = 300$ of the fifth layer receive input. Provide this area as a rectangular box with coordinates of the left upper corner, width, and height. You may assume that all weights of the neural network are non-zero.

(b) Provide the area of the input image from which the first perceptron in the seventh layer of the network receives input. Justify your answer briefly.

Solution

(a) The neurons receive their input from the previous layer using a convolution kernel. Hence their receptive field grows with the size of the convolution kernel. We obtain

Layer	receptive field			
	u_{left}	v_{upper}	width	height
5	400	300	1	1
4	400	300	1	1
3	398	298	5	5
2	393	293	15	15
1	383	283	35	35

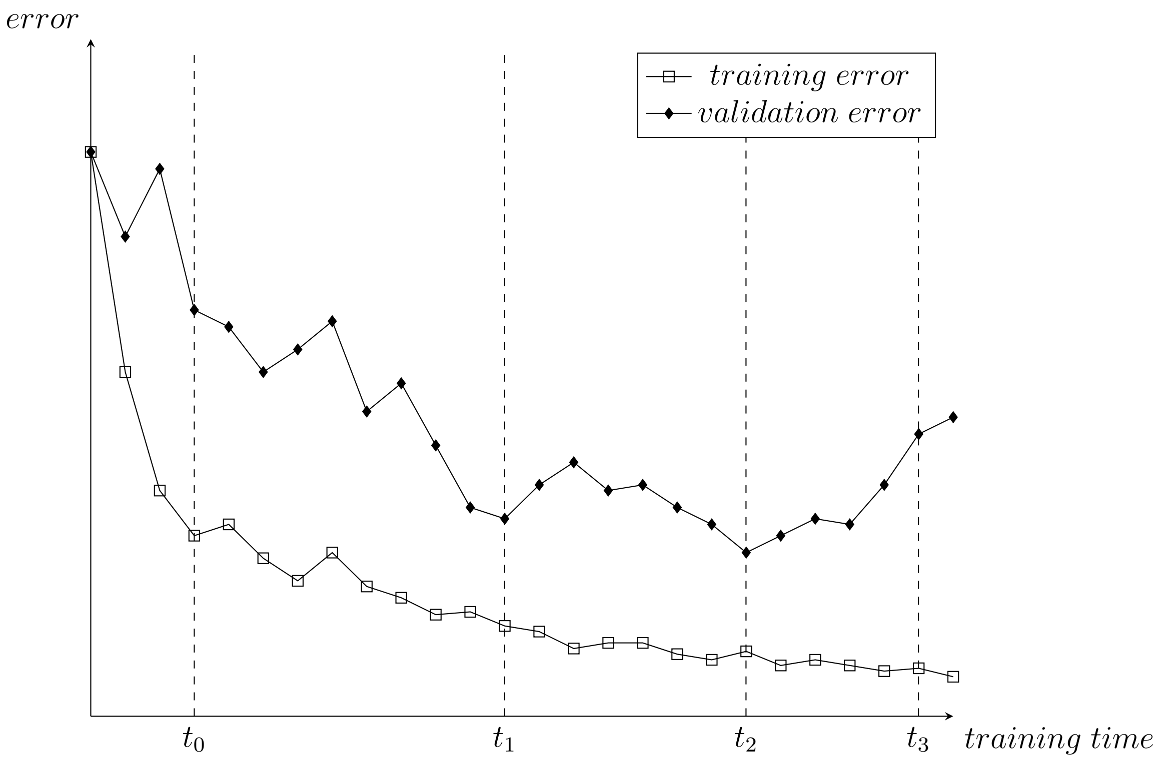
(b) Since the sixth and seventh layer are fully connected the neurons perceive input from all neurons of the previous layer. Hence, they obtain input from all pixels of the input image.

Question 9 (2 + 3 points)

The plot below shows both the errors for the training and the validation dataset during the training of a neural network.

(a) Four different points in time t_i are highlighted in the plot. At which of those points in time does underfitting occur? At which of those points in time does overfitting occur?

(b) At which point in time should the training be stopped? Why will further training not be beneficial. What is the name of this technique?



Solution

(a) t_0: underfitting
t_3: overfitting

(b) t_2: early stopping
Minimum with respect to the validation error. Further training only decrese training error but not validation error.

Gesamtpunkte: 60