Life Sciences und
Facility Management

ICLS Institut für
Computational Life Sciences

ADLS, Image and Signal Processing, Final module exam

Date: 21. June 2024
Lecturer: Norman Juchler

- Enter your name legibly below.
- Permitted aids: Writing utensils, four A4 pages of summary, calculator, dictionary
- Duration of exam **60 min**
- All sketches, calculations, derivations and considerations must be written on these sheets (front and back) and handed in. Additional sheets are not allowed.
- Provide answers in English
- Clearly cross out invalid answers and results. If it is unclear which result applies, no points are awarded.
- Do not write with pencil, colored pencil or other erasable pens

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Family name: **First name:**

Exercise	1	2	3	4	5	6	7	8	Total
Maximum	8	12	6	7	7	7	10	4	61
Result									

Grade: ____________

Good luck!

Question 1

8 P.

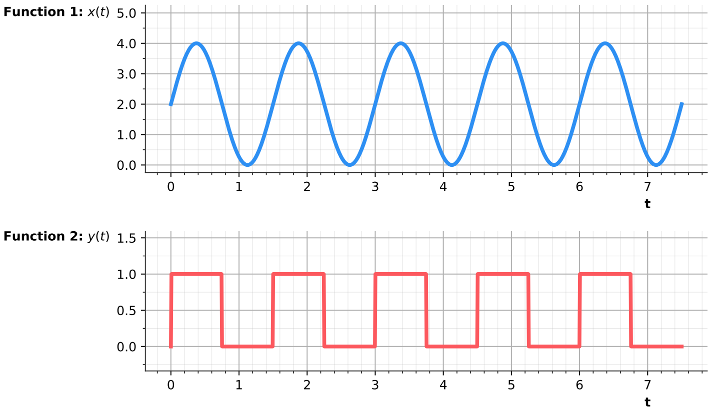

Figure 1: Two periodic functions

a) **Elementary signals** (3 P. possible)

- Provide a mathematical definition for the sinusoidal function 1 $x(t)$ seen in the figure above with all its parameters. (2 P.)
- Write a second definition that uses $\cos$ instead of $\sin$. (1 P.)

b) **Elementary signals**: Implementation (1 P. possible)

How would you create this data in Python? (If you were not able to solve task a), just use placeholders.)

```
import numpy as np
import matplotlib.pyplot as plt

def get_function1():
    t = ...
    x = ...
    return t, x

t, x = get_function()
plt.plot(t, x)
plt.show()
```

c) **Frequency** (2 P. possible)

Why do we distinguish between the frequency f and the angular frequency ω of a sinusoid function? Provide a formula that relates one to the other, and explain.

d) **Periodic function** (2 P. possible)

The second function in the graph $y(t)$ is another periodic function. Questions:

- What is the name of this function 2?
- How can you create the function $y(t)$ using $x(t)$?
- Hint: Note that the function has the same period as function 1.

Question 2

12 P.

Figure 2: Hubble telescope

a) **Applications of DSP** (4 P. possible)

Figure 2 shows the Hubble telescope, a satellite equipped with sensors and cameras.

Name four different applications of digital signal processing (DSP) that are relevant in this context. For each application, provide:

- The name and description of the application
- The type of signal being processed (input)
- The desired result of the processing (output)

b) **Analog-to-digital conversion** (2 P. possible)

When converting a physical signal into a digital signal, which are the main steps involved? Provide a scheme and name the most important elements.

c) **Sampling 1** (3 P. possible)

Explain the term undersampling.

- What does the term mean? (1-2 sentences)
- What main effects can undersampling have in a DSP system? (1-2 sentences)
- Explain the concept using the example of a image acquisition.

d) **Sampling 2** (3 P. possible)

Some facts about humans: The healthy human auditory system can hear acoustic signals with frequencies between 20Hz to 20kHz. Human speech is contained in the 100Hz - 4 kHz range.

As an engineer, you have the task of designing the audio system of a telephone that is capable of effectively recording and reproducing human speech. At the same time, the DSP system should be as cheap as possible.

- At what sampling rate should the microphone and loudspeaker operate?
- Provide a number and explain your choice in 2-3 sentences.
- What effect does your choice have on the listening experience? (1 sentence)

Question 3

6 P.

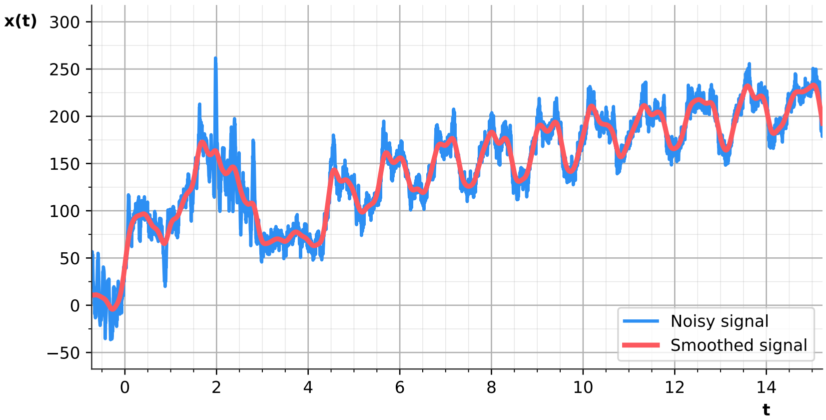

Figure 3: Noisy and smoothed signals

a) **Convolution** (4 P. possible)

Let there be two discrete-time functions $x[n]$ and $y[n]$. We want to convolve these two signals.

i Provide a mathematical formula for the convolution (1 formula)

ii Name a Python function that is able to compute the convolution (1 expression)

iii Give at least <u>two reasons</u> why convolution is relevant in DSP.

b) **Spatial filtering** (2 P. possible)

Figure 3 shows a noisy and a filtered signal.

- How can we achieve the smoothing effect using filtering in the time domain?
- Line out the approach in 1-2 sentences <u>or</u> provide Python code.

Question 4

7 P.

a) **Complex numbers 1** (2 P. possible)

Represent the complex number $z = 4 - 5i$ in polar form: $z = re^{i\varphi}$

b) **Complex numbers 2** (2 P. possible)

Regardless of the type of Fourier transform (continuous/discrete, periodic/aperiodic, 1D or 2D), the resulting coefficients or functions are generally complex-valued.

- Motivate why we look at amplitude and phase when dealing with Fourier transforms. (1-2 sentences)
- Can we reconstruct the original signal $x(t)$ if we know the amplitude and phase spectra of $X(\omega)$?

c) **Fourier series** (3 P. possible)

What can we say about the time-domain signal if we know that the coefficients of a Fourier series take the following values:

$$A_0 = 10, \qquad A_k = \frac{5}{\pi k^2}, \qquad B_k = 0$$

Name three properties about the time-domain signal $x(t)$.

Question 5

7 P.

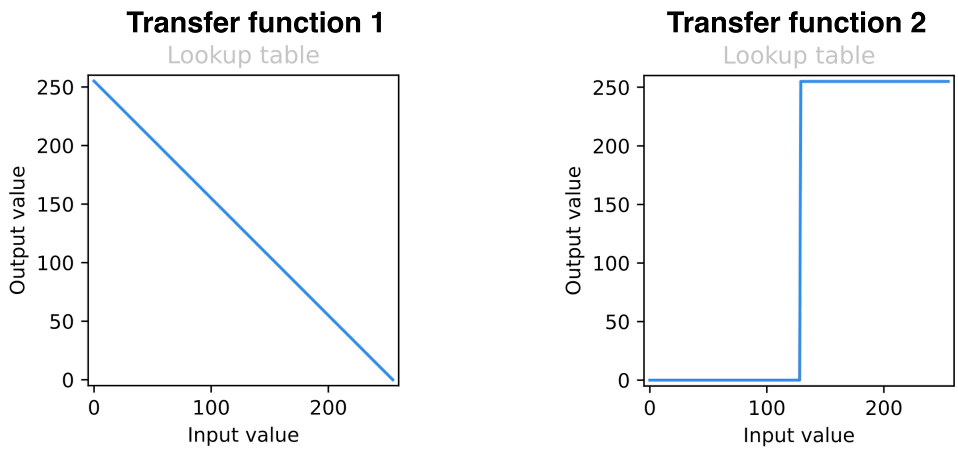

Figure 4: Transfer functions

a) **Image quality** (2 P. possible)

The lens of a camera collects the light and focuses it on the image sensor.
Name two types of distortions that can be caused by the lens optics.

b) **Color representation** (1 P. possible)

Assume we operate with 3-channel images with 8-bit unsigned integers. If we represent colors in the RGB space, how many different colors can we represent?
Hint: First answer the question how many values we can represent per single channel?

c) **Color operations** (2 P. possible)

Let be given the transfer functions of Figure 4. What happens, if we convert an 8-bit grayscale image using these transfer functions?

- Give a separate answer for the two functions.
- If applicable, describe the effect using one word.

d) **Color spaces** (2 P. possible)

The human vision system distinguishes between chrominance (color $\leftrightarrow$ cones) and luminance (brightness $\leftrightarrow$ rods) information. Is the RGB color space able to also separate these qualities of color perception? Explain! If the answer is no, provide an example of an alternative color space.

Question 6

7 P.

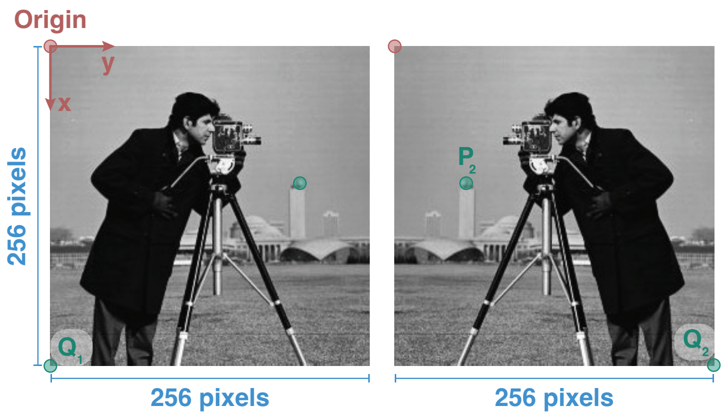

Figure 5: Transformation 1

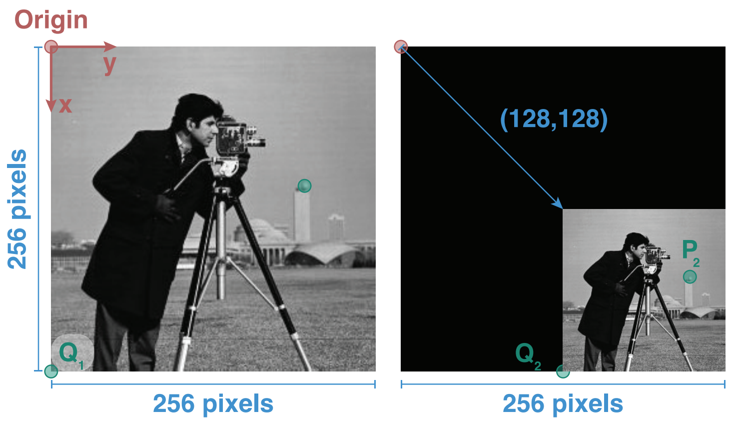

Figure 6: Transformation 2

a) **Inverse transform** (2 P. possible)

What is the inverse transform for an affine transformation A? What is it used for? Explain in 1-2 sentences.

b) **Affine transformations 1** (2 P. possible)

Take a look at the Figure 5 above. One can transform the image on the left using an elementary transformation to yield the image on the right. Which one? Name it, and provide the corresponding transformation matrix A

c) **Affine transformations 2** (3 P. possible)

Take a look at the Figure 5 above. The image is 256x256 pixels in size. Answer the following questions:

i What transformations are required to convert the left image into the right image. Suggest one possible sequence of elementary transformations to achieve this. Specify the transformations in words.

ii Write the affine transformation matrix $A \in \mathbb{R}^{3\times 3}$ as a product of elementary transformations. Note: The origin of the coordinate system is in the top left corner!

Question 7

10 P.

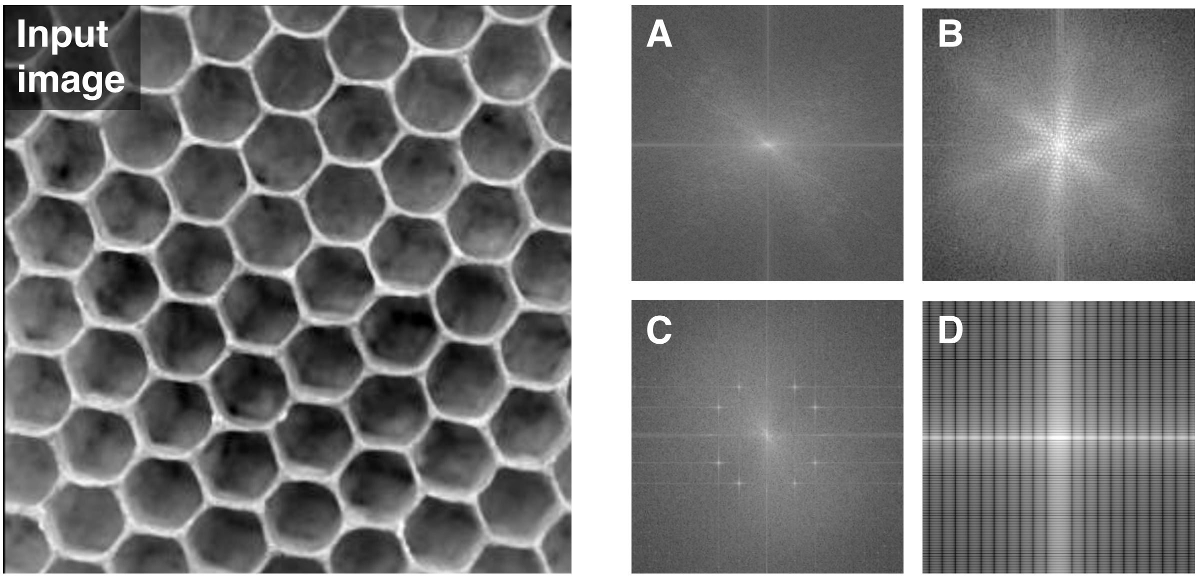

Figure 7: Left: Input image. Right: Candidate spectra

a) **Amplitude spectra** (2 P. possible)

Figure 7 displays on the left an image of a honeycomb. Which of the candidate spectra A-D is most likely the matching amplitude spectrum? Explain in 1-2 sentences.

b) **Band-pass filtering** (4 P. possible)

How would you apply band-pass filtering in the spectral domain, given an input image I? Provide a bullet point list with step-by-step instructions.

c) **FFT**: Code (4 P. possible)

We have learned that the following functions are used to compute the DFT of an image and its amplitude spectrum.

```
import numpy as np
import scipy.fft as fft
import matplotlib.pyplot as plt

def compute_spectrum(img):
    F = fft.fft2(img)
    F = fft.fftshift(F)
    F_abs = np.abs(F)
    F_abs = np.log(1+F_abs)
    return F_abs
```

Explain in your own words what happens in the individual lines of code. Give a reason why we are calling these functions.

Question 8

4 P.

a) **Miscellaneous** (4 P. possible)

Decide which of the following statements are true or false. Mark correct statements with a tick. Cross out the statements that are not correct in all details.

- Semantic segmentation and instance segmentation are essentially the same thing.
- In principle, color clustering can also be applied to grayscale images.
- Background removal is a kind of segmentation task.
- Morphological operations can be used to clean binary segmentation masks from small holes or segmentation noise.
- Erosion and sedimentation are common morphological operations.
- To detect edges in an image, one common approach involves estimating the local gradient using convolution kernels like Prewitt or Sobel kernels, and then applying a threshold to the gradient values.
- The following operation crops the image with a border of 'm' pixels and downsamples the image by an integer factor at the same time:
  `img[m:-m:2, m:-m:2]`
- The watershed method is sometimes used in connection with segmentation.