

**ARISTOTLE UNIVERSITY OF THESSALONIKI**

**SCHOOL OF INFORMATICS**

**DIGITAL IMAGE PROCESSING**

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**1. Justify why a two-dimensional  $N \times N$  moving average filter is separable.**

**ChatGPT:** A two-dimensional  $N \times N$  moving average filter is separable because it can be computed as the convolution of two 1-dimensional filters of length  $N$ . By breaking down the filter into two 1-dimensional filters, the computation can be performed more efficiently. This is because convolution in two dimensions requires  $N^2$  multiplications for each output pixel, while convolving two 1-dimensional filters requires only  $2N$  multiplications. This leads to a computational savings of a factor of  $N$ , which can be significant for large filter sizes.

**2. A CCD sensor records in its cells a) continuous space image, b) discrete image or c) digital image and why?**

**ChatGPT:** A CCD (Charge-Coupled Device) sensor records a discrete image. This is because a CCD sensor measures the amount of light that falls onto each cell, or pixel, of the sensor, and converts it into a digital value. This digital value represents the intensity of the light at that particular location and is stored as a number in memory. As a result, the image captured by a CCD sensor is a set of discrete values, each representing the intensity of light at a specific location, forming a discrete image. The CCD sensor does not record a continuous space image because the light that it measures is quantized into individual values, and it does not record an analog image because the measurement is converted into a digital signal.

**3. Is the lens of the human eye a low-pass or a band-pass system? Is the human eye lens an isotropic system (with respect to spatial axes) or directional?**

**ChatGPT:** The lens of the human eye is considered to be a low-pass system. This means that it allows lower spatial frequencies (longer wavelengths) of light to pass through with little distortion, while higher spatial frequencies (shorter wavelengths) are strongly attenuated. This

helps to form a clear image on the retina, as the majority of the detail in the image is contained in the lower frequencies.

The human eye lens is not an isotropic system with respect to the spatial axes. It is an anisotropic system, meaning that its properties vary with direction. The refractive index of the lens changes with the orientation of the incoming light, leading to different focusing properties in different directions. This anisotropy is important for correct focusing of light on the retina and is a key aspect of the functionality of the human eye lens.

#### **4. Is human vision panchromatic or trichromatic and why?**

**ChatGPT** Human vision is trichromatic, meaning it has three channels of color perception. This is because the human eye has three types of photoreceptor cells in the retina, called cones, which are sensitive to different parts of the visible spectrum. These three cones allow us to perceive a wide range of colors and hues, by combining their responses to different wavelengths of light.

In contrast, panchromatic vision would only have one channel for color perception, which would not allow for the discrimination of different colors and hues. The trichromatic nature of human vision allows us to see a rich and varied visual world, with the ability to distinguish between a wide range of colors and hues.

#### **5. What will happen if we have allocated memory for an image $a$ , with $N \times M$ pixels, starting at location $a[0][0]$ and we routinely access the location $a[N][M]$ ?**

**ChatGPT:** Accessing the location  $a[N][M]$  in an image  $a$ , with  $N \times M$  pixels, that starts at  $a[0][0]$  would result in an index out of bounds error. This is because the valid indices for the image are from 0 to  $N-1$  for the row axis and 0 to  $M-1$  for the column axis. Accessing a location that is outside of these bounds would result in an error, as the memory at that location has not been allocated for the image.

In many programming languages, accessing memory locations that are outside of the bounds of an array or matrix can lead to unexpected behavior and may cause the program to crash or produce incorrect results. It is important to ensure that all memory accesses are within the

bounds of the allocated memory, to avoid these types of errors and ensure the correct behavior of the program.

**6. What human vision characteristics are employed in the perception of grey tones through halftoning based on when printing a black and white image: low-pass or high-pass ones?**

**ChatGPT:** In the perception of grey tones through halftoning when printing a black and white image, low-pass human vision characteristics are employed. Halftoning is a technique for representing continuous tone images, such as photographs, in a binary (black and white) form for printing. This is done by dividing the image into small dots and varying the size of the dots to create the illusion of intermediate grey levels.

To achieve this illusion, the human visual system relies on its low-pass characteristics. The human eye is less sensitive to high spatial frequencies, and this is exploited in halftoning. The eye averages the size of the dots over a small region and perceives the average as the corresponding grey level. In other words, the eye acts as a low-pass filter, smoothing out the high spatial frequency information in the halftoned image and perceiving it as a continuous tone.

In summary, the perception of grey tones through halftoning in a black and white image takes advantage of the low-pass characteristics of human vision to create the illusion of intermediate grey levels.

**7. Find the difference equation of the filter:**

$$H(z_1, z_2) = 1 / (1 - az_1^{-1} - bz_2^{-1} - cz_1^{-1}z_2^{-1})$$

**ChatGPT:** The filter given by the transfer function  $H(z_1, z_2) = 1 / (1 - az_1^{-1} - bz_2^{-1} - c * z_1^{-1} z_2^{-1})$  is a two-dimensional filter. It can be expressed as a difference equation by substituting the z-transform of the input  $x(n_1, n_2)$  and the output  $y(n_1, n_2)$ .

Let  $x(n_1, n_2)$  be the input and  $y(n_1, n_2)$  be the output, then the difference equation can be written as:

$$y(n_1, n_2) = (1/a)*x(n_1, n_2) - (b/a)*x(n_1-1, n_2) - (c/a)*x(n_1, n_2-1) + (bc/a)*x(n_1-1, n_2-1)$$

This difference equation describes the relationship between the current output sample  $y(n_1, n_2)$  and the previous input samples  $x(n_1, n_2)$ ,  $x(n_1-1, n_2)$ ,  $x(n_1, n_2-1)$ , and  $x(n_1-1, n_2-1)$ . The coefficients  $(1/a)$ ,  $(-b/a)$ ,  $(-c/a)$ , and  $(bc/a)$  determine the magnitude and phase of the transfer function  $H(z_1, z_2)$  and must be chosen to satisfy the desired filter properties.

**8. Find the discrete-space 2D MT Fourier of a 3x3 moving average filter centred at (0,0).**

**ChatGPT:**The 2D discrete-space Moving Average (MA) filter is defined as:

$$h[n_1][n_2] = 1/9 * [ n_1=-1,0,1 \text{ and } n_2=-1,0,1 ]$$

The 2D discrete-space MT (Matched) Fourier Transform (FT) of a filter is defined as:

$$H(e^{j\omega_1}, e^{j\omega_2}) = \sum_{n_1=-\infty}^{\infty} \sum_{n_2=-\infty}^{\infty} h[n_1][n_2] * e^{(-j\omega_1 n_1)} * e^{(-j\omega_2 n_2)}$$

For a 3x3 MA filter centered at (0,0), the values of  $h[n_1][n_2]$  are:

$$h[-1][-1] = h[-1][0] = h[-1][1] = h[0][-1] = h[0][0] = h[0][1] = h[1][-1] = h[1][0] = h[1][1] = 1/9$$

Using these values, the 2D discrete-space MT FT of a 3x3 MA filter centered at (0,0) can be calculated as follows:

$$H(e^{j\omega_1}, e^{j\omega_2}) = (1/9) * (e^{(-j\omega_1(-1))} + e^{(-j\omega_1(0))} + e^{(-j\omega_1(1))}) * (e^{(-j\omega_2(-1))} + e^{(-j\omega_2(0))} + e^{(-j\omega_2(1))})$$

$$H(e^{j\omega_1}, e^{j\omega_2}) = (1/9) * (e^{j\omega_1} + 1 + e^{(-j\omega_1)}) * (e^{j\omega_2} + 1 + e^{(-j\omega_2)})$$

$$H(e^{j\omega_1}, e^{j\omega_2}) = (1/9) * (3 + 2\cos(\omega_1) + 2\cos(\omega_2) + 2\cos(\omega_1)\cos(\omega_2))$$

Thus, the 2D discrete-space MT FT of a 3x3 MA filter centered at (0,0) is

$$H(e^{j\omega_1}, e^{j\omega_2}) = (1/9) * (3 + 2\cos(\omega_1) + 2\cos(\omega_2) + 2\cos(\omega_1)\cos(\omega_2)).$$

