

1 Display of digital images

Name and briefly describe the different methods to adjust the image size

- **Nearest neighbour:** a new pixel takes over the value from its nearest neighbour
- **Bilinear interpolation:** new pixel value is calculated by the 4 nearest neighbours by weighted addition
- **Bicubic interpolation:** uses 2D splines to find the new value
- **Lanczos interpolation:** uses a Lanczos-Kernel to calculate the best fit for the new pixel

Lanczos interpolation provides the best mathematical fit but needs the most processing power.

Explain the characteristic properties of the CMYK, RGB and HSB Color models CMYK (Cyan Magenta Yellow Key) is a subtractive color model and usually used in print media. The values range from 0-100 (standard representation) and all colors combined produce black.

RGB (Red Green Blue) is an additive color model and used in displays. The standard representation is 0-255 (for 8 bit color depth) and all colors combined produce white.

HSB (Hue Saturation Brightness) is equivalent to HSV, HSL and HSI. It can be imagined as a cone with the Brightness as the height, the saturation as the distance from the center and hue as the angle of the point relative to red which is 0 degrees. Because the brightness corresponds to the grayscale version of the image, colors are preserved.

Explain the properties (and advantage) of the Lab-color model (Assume no difference between the Lab (1931) and the $L^*a^*b^*$ (1976) for this question). The Lab color model describes all perceptible colors. Colors are represented by a Lighness (L) value as well as an a and b values which can be positive or negative and describe a point on a color matrix. The a value describes the color intensity between red and green while the b value describes the intensity between blue and yellow.

Because of the nature of the system it is independent of the way the color is produced. The values represent how a standardized observer perceives the color under standardized lightning conditions. It therefore is independent of the machine and comparable. Because of this the lossless conversion into a different color space is possible with color profiles.

What is the Gamut and make a simple drawing of the Lab-color space, the RGB and CMYK gamut? The Gamut is a certain complete subset of colors. It represents all colors that a certain media can reproduce for example a computer monitor or a printer with a certain type of ink and paper.

L^*a^*b color space: A triangle tilted to the left with a rounded tip. The edges represent red, green and blue, the middle is white.

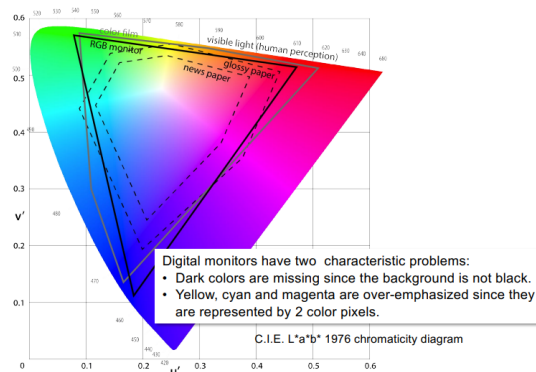


Figure 1: Color Gamut

RGB: inside the Lab, RGB is a triangle with yellow, cyan and magenta over-emphasized because those colors are represented by two pixels.

CMYK: inside the Lab, CMYK is mostly narrower and resembles a hexagon.

What do we understand under the term ICC-Profiles and when are they used? Make a simple drawing how they are used between a camera, a monitor, and a printer. Different devices use different methods of displaying color. It is therefore necessary to convert between those to display images on different devices.

An ICC profile defines a mapping to convert the profile connection space (PCS), which is essentially the connecting color space (either CIELAB or CIEXYZ) to the local color space and vice versa.

For the example, a camera takes a picture representing RGB values. Those are converted to the CIELAB color space with the ICC profile of the camera. Importing that image to a PC and viewing it, the PC uses the ICC profile of the monitor to map the CIELAB values to the RGB values that the monitor can display. When sending the (possibly edited) image to the printer, it converts the values back to CIELAB, sends it to the printer which then converts it to CYMK which it can print, all with ICC profiles.

Consumer grade devices usually have embedded color profiles. Those often are inaccurate which makes calibrating them necessary when doing critical color work. The calibration also produces an ICC profile.

What do we understand under the term color temperature and when should a white balance (digital camera) be carried out? Most occurring light is actually not perfectly white. It has a red to blue tint to it. This color can be described by the black body radiation at a certain temperature. This is called the color temperature.

Candle light is rather red and has a color temperature of about 2000 Kelvin, midday sun is almost perfectly white at around 5500 K and dark blue sky has a color temperature of 9000 K and higher.

White balance is the act of compensating for the abundance of red/blue to get a neutral image. Most digital cameras already do that automatically but

when color is critical it can be done manually by placing a known neutral object in the frame and setting that as a reference in the image processing software.

2 Improving contrast & brightness

What is a transfer curve (look-up table) and make a simple drawing for a transfer curve leading to a

- contrast enhancement
- brightness enhancement
- gray scale inversion (Black → white, white → black)

(Assume a gray scale image with Black=0 and White = 255 as original image).

A transfer curve is essentially a function that translates a certain pixel value to a different output value. To speed up processing it can also be displayed as a LUT.

The graph has the input value on the x-axis and the output value on the y-axis.

For contrast enhancement a S-curve is appropriate. Darker values get darker while brighter values get brighter.

For brightness enhancement you want dark values to get brighter but bright values not to clip. The curve will look like a limited growth model (steep at the beginning and flattening towards the end).

For inversion the graph will go from the top left corner to the bottom right corner.

Describe the Gamma correction and make a drawing of the transfer curves for $\gamma > 1$ and $\gamma < 1$. The gamma correction is a non linear transfer curve described as $y = x^\gamma$. When γ is greater one, the image will appear darker. The curve kinda looks like the right side of a half U. When it's smaller than one, the image will appear brighter and it will resemble the curve upside down.

What is the histogram of an image and how is it generated? The histogram is a representation of all pixel values contained in an image. It is usually generated using the grey values but can also be generated of R,G,B,a*,b*,L,... values of the pixels.

It is generated by counting the amount of pixels with a discrete value from relative 0 to 1 (0-255 for 8 bit images) and plotting them onto a graph whereas the x-axis resembles the value and the y axis the (relative) number of pixels.

What is the sum (cumulative) histogram and what is meant by (global) histogram equalization? A cumulative histogram adds the amount of pixels with increasing value instead of displaying the count of pixels per value. If there are 2 pixels with a value of 0 and 5 pixels with a value of 1, it will count 7 cumulative pixels at a value of 1.

With global histogram equalization it is assumed for the grey values to be Gauss bell shaped. The cumulative histogram then is the error function of that

distribution. The error function can be used as transfer curve to get a more homogeneous distribution of the grey scale images. It increases the contrast of the image but the theoretical approach is only valid for continuous functions.

Make a simple drawing of a histogram / sum histogram and indicate how the lower 3% and the higher 3% of the pixel values can be determined and subsequently set to black or white in order to improve the dynamic range of the displayed image, respectively. Drawing of a histogram and a cumulative histogram. In the cumulative histogram, look for the value at 3% and 97% then create a transfer curve intersecting the x-axis at the 3% value and the upper bound at the 97% value.

3 Filtering

Which two “families” of filter operations do you know and what is their major difference? There are linear filters and ranking filters. While linear filter operations always use the same algorithm for filtering and only specific numbers used in the operator produce different results, ranking (aka non-linear) filters deploy strategies. For example sorting the neighborhood and replacing the central pixel with a selected value.

How do linear filter operations work in general? First a filter mask is defined. A 3x3 filter mask for example takes all pixels surrounding the central pixel into account. For each position on the mask a value is defined. To determine the new value of the central pixel, each pixel value is multiplied with the corresponding filter value. Those values are added together to create the new pixel value of the central pixel.

This is done for each individual pixel.

Explain the application of a (3x3) Low-pass filter in the space domain (=based on the concept of linear filter operations). The low pass filter basically averages the surrounding pixel values. A simple low-pass filter could have a value of 1 for each position of the filter mask. Because noise is randomly distributed, it will get averaged out. Therefore a low pass filter can be used to reduce noise but can reduce the sharpness.

What do we understand under the term Differential of Gaussians (DOGs)? The differential of Gaussian filter is an algorithm to enhance features. It works by blurring an image (low pass for example) with two different standard deviations and subtracting the more from the less blurred one. The result is a removed background and eliminated noise.

What do we understand under the term Sharpening? Sharpening is the enhancement of detail to improve the visual appearance of images.

It can be done by calculating a second derivative (Laplacian) and adding that to the original image.

The second derivative is zero at areas of constant intensity and non-zero at the onset and end of an intensity step/ramp. It is also zero at along a constant

Cross section through an edge

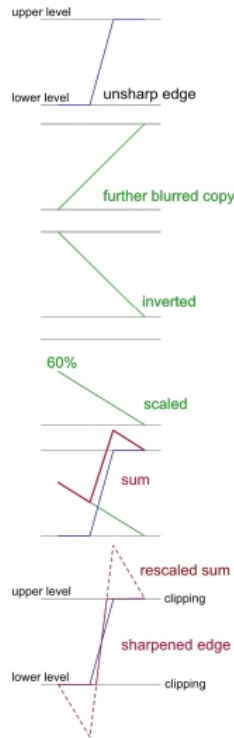


Figure 2: USM: Cross section through an edge

slope. It therefore contains the edges in an image which usually provide detail. Adding that to the original image will lead to better sharpness.

What is meant by Unsharp Masking (USM) and how does it work and make a schematic drawing of a cross-section of an edge. USM is a method of enhancing edges by subtracting a blurred version of the image from the original image. The resulting image will be clearer but losses of accuracy in regard to the subject are likely.

Cross section description:

Graphs with upper and lower level.

Original image: edge quite steep from 0 to 1

Blurred copy: edge less steep, then inverted.

Inverted, scaled blurred image: inverted and instead of 1 as max 0.6 or so.

Then sum is made (sum of inverted image equals subtraction of non-inverted):

Results in zig-zag line around the edge

Finally the sum is rescaled: values out of bound get clipped and result in sharpened edge, steeper than original.

Explain Cross Correlation Averaging. In CCA a reference area which is usually from the original image, is shifted over the image itself. For each

point the similarity between those two images is then calculated through a mathematical function. This is the cross correlation function.

The most similar positions are then averaged, which improves SNR.

It is a linear filter operation with the Kernel being the selected reference area.

Explain the Median filter The median filter is a ranking operator. It calculates the median (sort by value and select the central middle one) of the pixel values in the kernel and sets the new value as the median value. It is effective in eliminating outlier pixels such as noise from hot and cold pixels (salt and pepper noise).

How does the Kuwahara filter work? The Kuwahara filter is used for smoothing and adaptive noise reduction. It aims to smooth the image while preserving edges.

First a square window around a central pixel is taken, subdivided into 4 smaller square regions overlapping at the central axis.

Then the arithmetic mean and standard deviation of the four regions are calculated. The central pixel takes the value of the mean in the square with the lowest standard deviation.

4 Image segmentation

What is meant by binarization and explain how a suitable threshold may be determined. Binarization aka thresholding is act of setting pixels to either 1 or 0 depending on the value. This way an object can be separated from a background.

The threshold can either be set manually or automatically. The histogram can usually be approximated by bell shaped functions. One represents the object and one the background (there might be more than two bell shaped functions in more complex examples). A good threshold value is the intersection of those two curves.

Another way of getting a threshold is by machine learning.

Explain the Rolling-ball background subtraction method based on a simple schematic drawing. The rolling ball background subtraction method is often used for gels and the like. The approach is simple: imagine the greyscale image is plotted onto a 3D graph with the value as height of the pixel (=data point). Now a "rolling ball" with a certain size is rolled over the bottom of that graph and it's height is recorded. Peaks bigger than the ball will cause it to move into it while it will roll over smaller peaks.

Now the height of the ball is subtracted from the original pixel value eliminating all objects that are bigger than the ball. If set correctly, the size of the ball is bigger than the largest object in the image that is not part of the background leading effectively removing the background from the image.

Explain the classical erosion and the dilation operation based on simple schematic drawings. Erosion turns pixels off and dilation turns pixels on depending on the neighborhood.

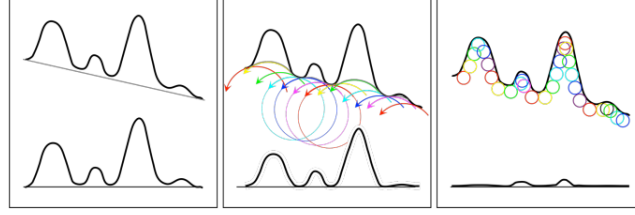


Figure 3: Rolling Ball method

The classical erosion method is to set the central pixel to the background value (white, 0) if at least one of the 3x3 surrounding pixels is white.

Dilation on the other hand sets the central pixel to the object value (black, normalized 1) if at least one pixel in the 3x3 neighborhood is black.

```

1  1  0
0  ?  1
0  1  1

```

Erosion would set the central pixel (?) to 0 and Dilation would set it to 1 in this example.

Usually there are the parameters count and iterations. Count defines how many of the surrounding pixels need to be 0/1 to alter the central pixel and iterations is how often the process is carried out.

What is the Euclidian distance map (EDM), what are ultimate eroded points (UEPs) and how does the watershed operation work? The EDM shows the distance of a pixel to the edge it belongs to. It is obtained by iterative erosion while counting the number of steps needed to remove the pixel. The amount of required steps is represented as the gray value of the new pixel. It can be used for erosion after thresholding as it is less susceptible to artifacts.

UEPs are local maxima obtained through the EDM. They can be interpreted as centers of circles.

The watershed operation is an application for EDMs and used for separation of objects. It works by taking the EDM of an image and determining the watersheds (the pit between two intensity peaks). The minimum of that peak is used to separate two overlapping objects.

What is meant by the term neighborhood code and how might it be used? Neighborhood code is used to speed up the decision whether to keep or delete the central pixel in dilation, skeletonization, erosion and similar methods.

Assuming a 3x3 neighborhood operation there are 8 positions for the surrounding pixels. The value of each pixel can be described as either 1 or 0. Per definition we start at the right hand side of the central pixel and move counterclockwise. This results in a binary number representing the surrounding pixels.

This is done for each possible configuration, linked with a decision (keep or delete) and is stored in a Lookuptable (LUT).

This LUT is now used to make decisions based on the surrounding pixel value.

```

1  1  0
0  ?  1
0  1  1

```

This example would produce a value of 11001101.

5 Image analysis

Make an outline of the workflow of image analysis. First the data is acquired through a camera, scanner, etc..

Then the image is corrected (color correction, background correction, noise reduction) and enhanced (contrast/brightness, sharpening, edge detection,..).

After the enhancement the image is binarized either manually or automatically.

The binary image is then edited (morphological transformations, EDM, watershed, Boolean combinations, etc.).

The edited image is then measured resulting in a list which can be used for statistical analysis.

The whole process is then automated to make batch processing possible. The automated system has to be controlled.

Name the four major groups of feature measurements and give a few examples

- **Size:** Area, perimeter, largest diameter, angle of the largest diameter against axis, Feret diameters (diameters projected onto x and y axis). Size measurements require a calibration to translate pixels into real world dimensions.
- **Shape:** The shape of an object like square, spherical, triangular, etc.. The topology, dimensionless ratios (Form factor), fractal dimensions.
- **Intensity:** The brightness in of an object in relation to the background. Useful if the intensity corresponds to concentration for example.
- **Location:** Absolute coordinates of the central pixel, distance from other objects

What is the form factor (F) and how is it defined? The form factor is the deviation from the shape of a circle. It is defined as

$$F = \frac{4 * \pi * area}{perimeter^2} \quad (1)$$

It is the same as the compactness which is defined as the ratio between the area of the object to the area of a circle with the same perimeter.

Draw a simple point pattern and construct the area associated with a (central) point using the Voronoi-approach. The Voronoi diagram aims to find the nearest neighbors of a point. In cells, the nearest neighbors are points which contribute to the borders of that cell.

To construct one, we need a point pattern. We then connect the central point with the outer points and make a perpendicular line at $1/2$ of the distance on each line. The Voroni diagram is the resulting shape enclosing the central point. All points contained in that area are closest to the central point.

6 Machine learning

Describe and make a drawing of a typical machine learning situation

A typical machine learning situation in imaging is object recognition.

First we need some training data with known results. This data is then fed into the chosen machine learning algorithm which then creates a so called classifier.

The classifier is then tested against independent test data with known results to calculate a hit rate (x% correct y% incorrect classifications). The classifier is then refined by providing more training data or using a more suitable machine learning algorithm until the hit rate is sufficient.

This classifier can then be used on real data.

7 Fourier domain processing

How does Fourier analysis work? Explain it, using a rectangular-function According to Fourier any periodic function can be decomposed into a sum of cosines and sines.

Using a rectangular function as an example, the first approximation is just a sine/cosine wave. Then a second wave with a higher frequency gets added/subtracted from that wave creating a better approximation, followed by a third one with higher frequency is added/subtracted and so on yielding a better approximation to the rectangular function with each added layer.

Through Fourier transformation the amplitude can be plotted against the frequency.

How may a crystal structure be described (Use the terms unit cell, base vectors, and asymmetric unit)? A crystal structure is a pictorial representation of a periodic function. A crystal lattice is defined by a **unit cell** which is repeated along a point grid which is defined by two base vectors (often referred to as \vec{a} and \vec{b}).

A unit cell is made up of asymmetric units that are arranged symmetrically.

There are several options for symmetry operations like a rotation around a point or mirroring along a line.

Which symmetry operators do you know for point group symmetries and make a simple drawing for each one applied to the letter “L”

There are several options for symmetry operations like a rotation around a point (eg. 0° , 60° , 90° , 120° , 180°) or mirroring along a line.

Explain Fourier domain filtering (optical filtering) for a noisy electron micrograph of a protein lattice. Make a simple schematic drawing too First the diffraction pattern of light at a photographic negative is recorded in

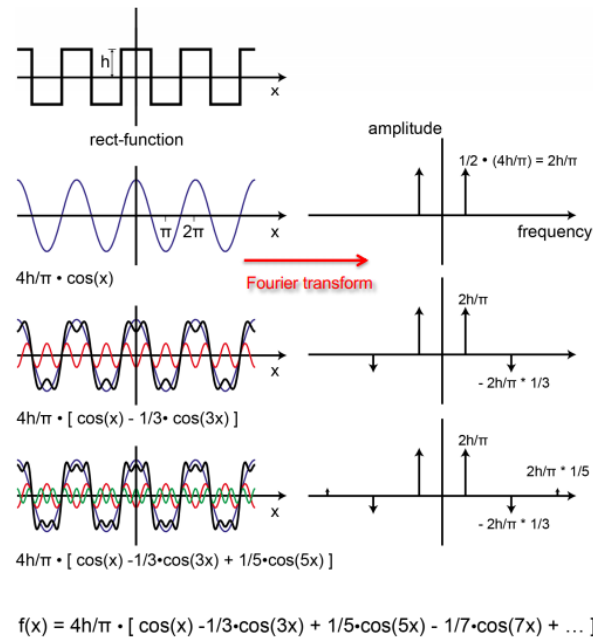


Figure 4: Fourier analysis

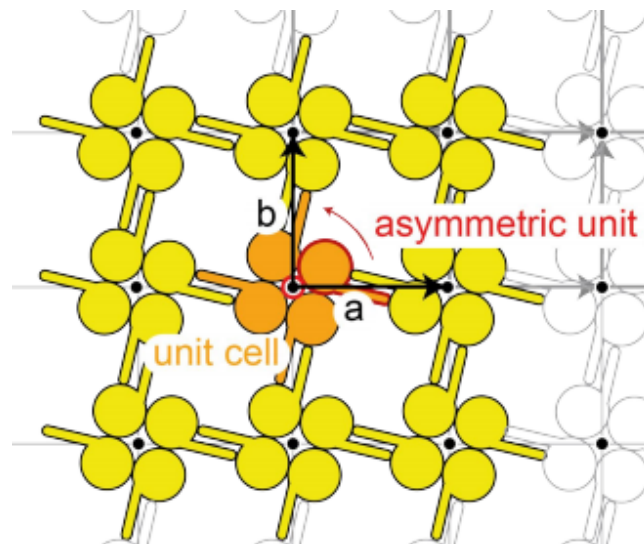


Figure 5: Crystal lattices

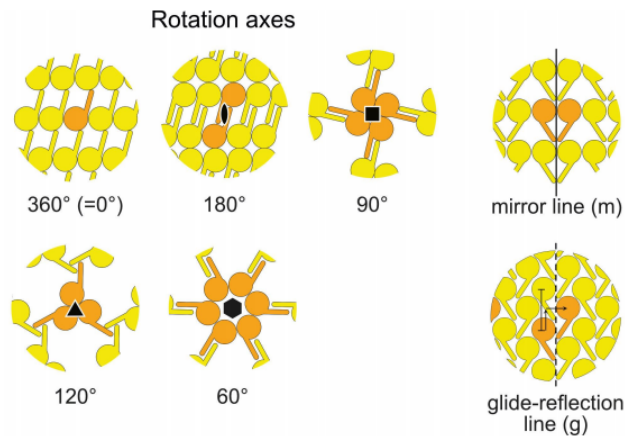


Figure 6: Symmetry operators

the back focal plane of a converging lens. This is equivalent to a mathematical Fourier transform.

That diffraction pattern is then used to create a filter mask by punching out holes from an opaque mask like copper foil. That mask is placed in the back focal plane of the lens. Now the filtered image appears in the image plane of the lens. This is equal to a reverse Fourier transformation.

Describe the four steps used in the characterization of the reciprocal lattice in a diffraction pattern.

1. Find diffraction maxima
2. guess lattice lines and first order spots (0,1 and 1,0)
3. determine base vectors \vec{a} , \vec{b}
4. determine resolution of the image by looking for the highest order diffraction spots

Low- and High pass filtering in the Fourier domain: Make drawings of cross-sections with the x-axis as frequency axis and the y-axis as amplitude axis. As the Fourier transformation produces an image on the frequency domain, it is possible to use that to cut out high or low frequency signals from an image, basically acting as high or low pass filter.

For a low pass only an inner circle is used as filter. The outer part is black while the inner part is let through. On the outer part the amplitude is 0 and in the circle it is 1.

For the high pass filter we cut out the low frequencies by cutting out an inner circle. The amplitude outside the circle is 1 and in the circle it's 0.

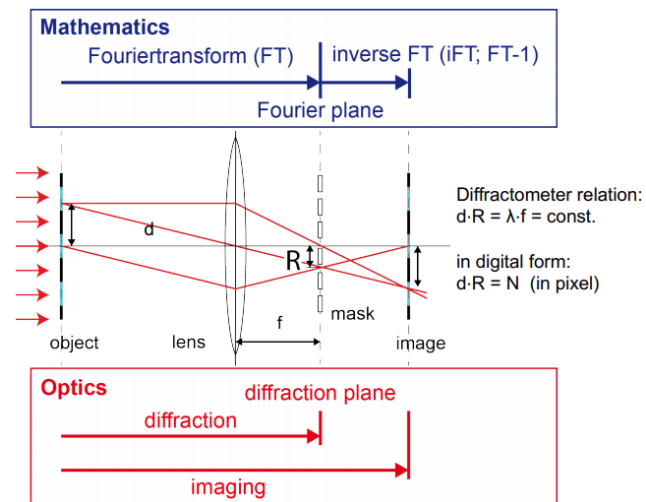


Figure 7: Optical Fourier transformation

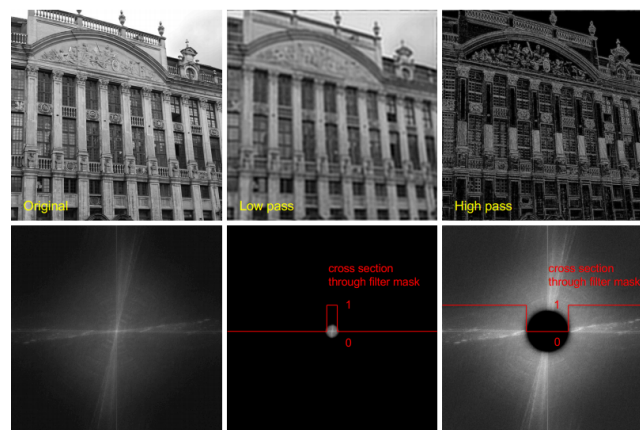


Figure 8: Fourier transform pass filters