Signal processors in digital cameras and digital film cameras

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What is a digital camera?

- Types of digital cameras:
  - Compact cameras - are characterized by small size, simplification and automation of operation.
  - Digital SLR cameras (DSLR - Digital single-lens reflex) - larger sizes, complicated operation.
  - Mirrorless cameras - no mirror system, small size.
- Digital cameras are optoelectronic devices that are used to record static images and store them in digital memory.

What is digital film camera?

Digital film camera

- A device similar to a camera. A heavy, expensive, professional camera variation. A movie camera takes a sequence of high-quality photos in very short time.
- The current technique of film cameras allows you to film in various frames:
  - 23.976 -> 24 (NTSC region)
  - 25 (PAL region)
  - 29.97 -> 30 (NTSC region)
  - 50/60/120/240 etc.
- And in higher resolutions:
  - Full HD - 1920 x 1080 px
  - 4k - 3840 x 2160 px
  - 6k - 6144 x 3456 px

Construction of a digital photo camera and digital film camera

- Lens - built-in or removable
- Photosensitive matrix - non-replaceable
- LCD display - movable or stationary
- Memory card slot
- Microphone
- Neutral density filters
- **Signal Processor - processing of the recorded image**

Construction of a digital camera

- Using light, the camera transforms a fragment of the surroundings seen from a specific point into its flat image.
- Components:
  - Lens - brings a sharp image inside the camera and focuses it precisely on the matrix.
  - Aperture - regulates the light output.
  - Shutter - shutter speed adjustment.
  - Matrix - collects light and converts it into electrical impulses.
  - Memory card - electronics "translate" the impulses into an image saved on the memory card.

Matrices in digital cameras and film cameras

- The digital recording of a photo or video requires an element - a matrix - which allows to record the visual form created by light and shadow thanks to the lens.
- Two types of matrices are commonly used:
  - CCD - Charge-Coupled Device
  - CMOS - Complementary Metal Oxide Semiconductor

CCD matrices

- The CCC matrix is a photovoltaic plane consisting of capacitors that convert light energy into electric current.
- Tiny lenses focus light on each of the millions of capacitors on the photosensitive layer.
- CCD arrays are most often defined by defining the number of capacitors. The value is given in megapixels.

CMOS matrices

- CMOS arrays work in the same way as CCD arrays.
- The light falling on the silicon crystal forming the pixels generates electric charges in them.
- So, a single pixel in CCD and CMOS sensors is practically the same. Only the "surroundings" of the pixel in the CMOS matrix are completely different.
  - Each pixel has its own charge-to-voltage converter.
  - Each pixel has its own "address" and its content can be read in any order.

CMOS matrices

- The electrical circuits integrated with each pixel take up space on the matrix and therefore the fill factor, i.e. the ratio of the sum of the areas of all pixels to the area of the entire matrix, is smaller for CMOS matrices.
- As a result, the CMOS sensors are slightly less sensitive. Part of the light falling through the lens hits the electronic components built into the matrix and is not converted into electric charges.
- This drawback can be easily compensated for by marking the matrix after its manufacture and taking into account the differences between pixels in the digital camera program.

Differences between CCD and CMOS matrices

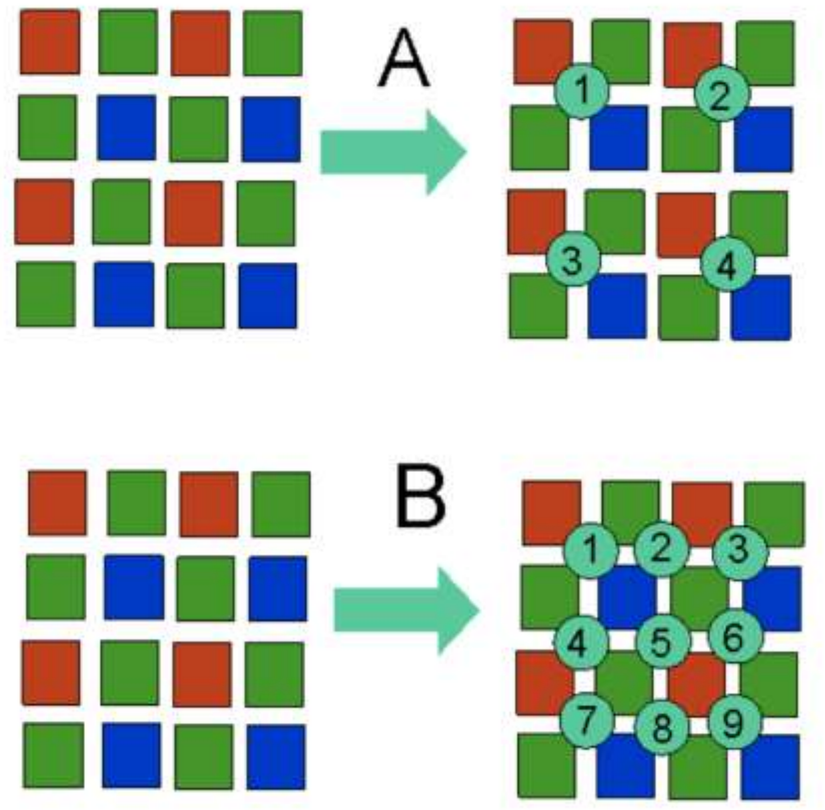
CCD	CMOS
The content of a single pixel cannot be read. You have to read the content of the entire matrix and then select the pixel you are interested in. This makes their operation quite slow.	You can read the contents of any number of pixels and in any order, just like reading the contents of computer memories. Therefore, they work much faster.
The matrix has one charge to voltage converter and one A / D (voltage to number) converter. The content of all pixels is read sequentially by this chip.	Each pixel of the CMOS matrix has its own charge-to-voltage converter and the system that reads the pixel content already reads the voltage generated by the light falling on that pixel.
Due to their construction, CCD arrays consume more power during operation.	They consume less electricity, which allows you to take more photos with a battery once charged.
Larger fill factor, i.e., the ratio of the pixel area to the area of the entire matrix.	Lower fill factor, because some of the matrix surfaces are occupied by circuits converting the charge into voltage.
Less noise.	More noise.

Bayer formula - signal processors

- There are two ways to record the image on the matrix:
  - Using a triple CCD.
  - With the use of Bayer mosaics.
- Photodiodes present on photosensitive matrices do not distinguish colors, they only register light intensity.
- Each photodiode is under a filter with a specific color.
- The filter elements are placed on the mosaic according to the pattern G, R, G, B.
- The image is created as a mathematical calculation of the values of adjacent pixels.
- The **signal processor** then converts the output data to obtain a graphic file.

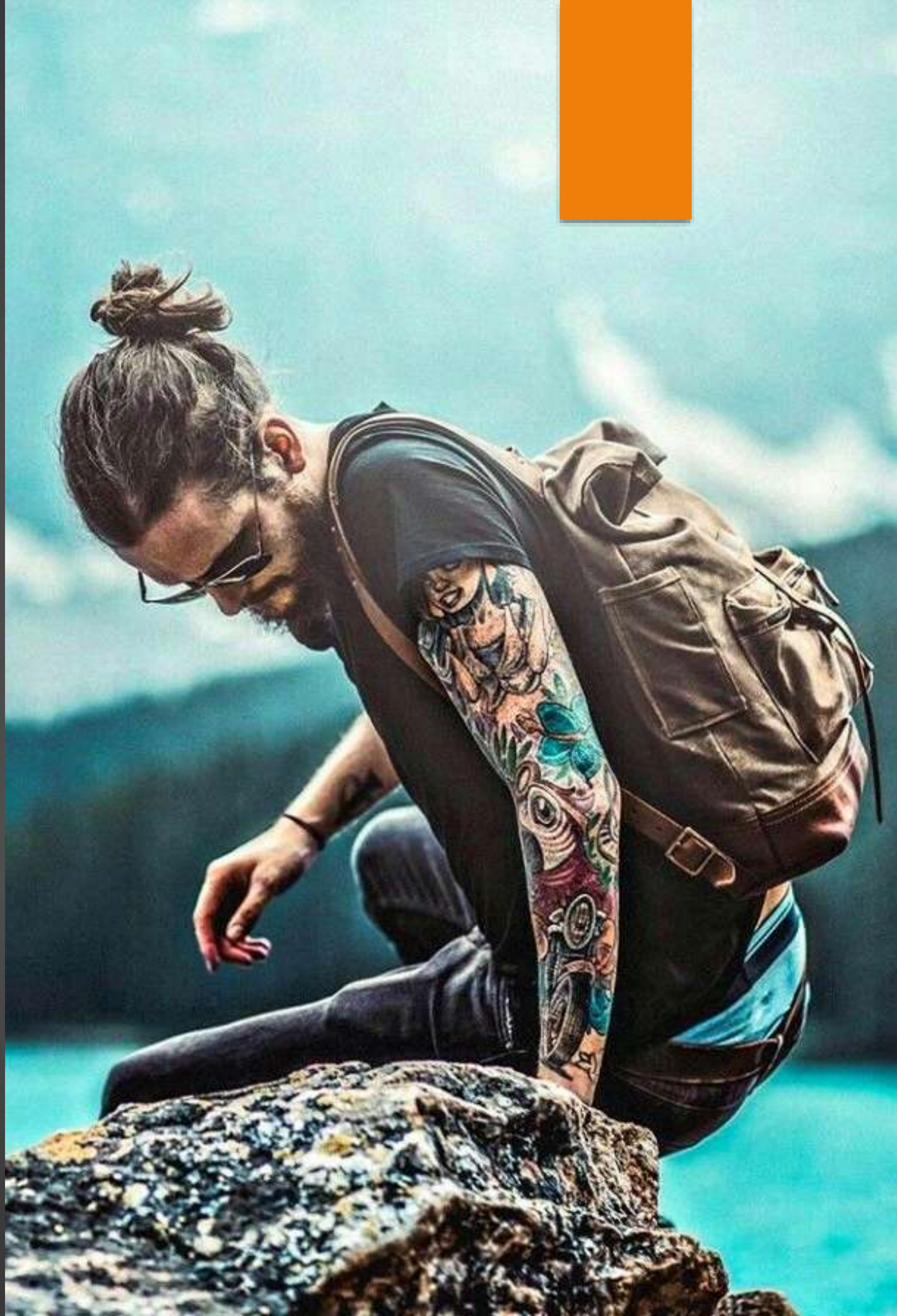
Demosaic

- The signal processor calculates the color and brightness of each pixel.
- The input data is compared with the values of the neighboring pixels and using the demosaic algorithm the final brightness and color value is calculated.
- In part A, one point of the image is reproduced from the intensity of light registered on 4 adjacent pixels. Maryca 4x4, or 16 pixel, gives a picture with a resolution of 2x2.
- In part B the procedure is similar but the points for creating a photo are taken so that some pixels (except the completely outer ones) are taken to demosaic several times. For example, the intensity recorded by the first (left and top) "blue" pixel is used to reproduce the colors of points 1, 2, 4 and 5. This gives a picture with a resolution of 3x3.



Noise and its reduction - digital cameras

- Other electronic devices in the immediate vicinity of our digital camera or film camera can also affect the noise.
- The photosensitive matrix, like most electrical devices, heats up and the higher the temperature it reaches, the higher the probability of noise. The noise also increases with the amplification of the signal, when there is little light and the pixel receives not enough light.
- The matrix in weaker lighting simply "sees" less, and by amplifying the signal we get more noise.



Reducing noise - digital cameras

- The simplest solution is to use a lower ISO sensitivity.
- Digital cameras offer built-in noise reduction systems at higher ISO sensitivities and longer exposures.
- If we set the appropriate level of denoise for higher ISO sensitivities, we should have a compromise between reducing noise and washing out the finest details.
- If we overdo noise reduction, we get a blurry image that will be devoid of details.
- When it comes to long exposures, denoise is the process of taking a second photo without opening the shutter, thanks to which the camera makes sure what is the image and what is noise and uses appropriate algorithms to remove the former.

Image sharpening - digital cameras

- Due to the fact that the color value and brightness value of each pixel is calculated based on the neighboring values, some softening of the image appears.
- In order for the image to be rich in detail, the signal processor performs the sharpening of edges, contrasts and contours.
- This process is based on increasing the contrasts on the edges of objects. Remember not to over-sharpen, as this can create a halo around the subject, such as a black and white border.

Lenses - autofocus

- The autofocus system is one of the best features of modern digital cameras.
- We divide AF systems mainly according to the methods by which the camera decides about the focus of a given element in the frame. Here we distinguish two basic types:
- Phase and contrast detection.
- A hybrid solution that combines these two systems into one, more precise.

Phase detection

- Phase detection is used primarily in SLR cameras in which the matrix is obscured at the time of framing and only exposed during exposure.
- The camera focuses with sensors located outside the main image sensor, which are located under the mirror chamber.
- The light passes through the lower, semi-transparent part of the primary mirror, then is reflected from the secondary mirror, from where it is directed downwards onto the AF sensors.
- The sensors use the phenomenon of parallax by selecting two rays of light and calculating the distance between them. If the rays are too far apart, the subject is in focus. If too close, behind the subject.

Contrast detection

- This layout is simpler. It does not require additional sensors, because the whole thing is done by measuring the contrast in any part of the frame.
- The camera simply measures the contrast at the user-selected location, and by moving the lens of the lens back and forth, it selects the moment where the contrast, in the selected segment, is at its highest.
- The out of focus image is the least contrasting.
- By sharpening it, the image becomes clearer, and thus the contrast at a given point is greatest at the moment when the image is in focus.

Automatic selection of exposure parameters

- Exposures can be controlled using parameters such as:
  - The size of the aperture.
  - Setting the shutter speed.
  - ISO value.
  - And of course the amount of light that surrounds us.
- Parameters such as the aperture value and shutter speed are selected on the basis of the values measured by the photosensitive sensor built into digital cameras. You can also find automatic exposure selection in smartphones and sports cameras.

Automatic selection of white balance

White balance and its automatic

- Manufacturers are constantly improving algorithms that analyze the recorded image. This is to choose the right white balance correction to make the photo as faithful as possible to reality.
- The algorithm searches for the brightest point in the recorded image, assuming that it is close to white, and on this basis it makes a correction so that it really is a white point in the image.
- It then applies this correction to the entire photo.

Digital image stabilization

- This type of image stabilization is based on advanced algorithms that detect movement in the resulting image.
- Electronic Image Stabilization is useful for handheld shooting by eliminating hand shake.
- Motion detection does not use a gyroscope, but appropriately prepared algorithms in the image processor, which analyzes the signal from the matrix pixels on an ongoing basis.
- It is a stabilization of the passive type.
- The image recorded after applying electronic stabilization has a slightly lower resolution and field of view than photos taken without the stabilizer.

Backlight Compensation - Digital Movie Cameras

- The basic function already equipped with most of the available cameras, it compensates for the backlight effect.
- Foreground obscuration effect appears when the camera is facing a strong light source. BLC technology somewhat eliminates this problem by brightening the foreground.
- While this brightening is also related to brightening the background, this function is most useful because it enables foreground observation and generally improves the image under the conditions described.

WDR and D-WDR technology

- *A system allowing to obtain a wide dynamic range of the image.*
- *The camera uses special algorithms to analyze the image exposure and dynamically changes the values of underexposed and overexposed pixels of the camera sensor in order to show the underexposed elements in the image.*
- *The effect of this function is the possibility of obtaining a clear and relatively uniformly exposed image both in dark and very bright parts of one scene.*

Image compression

- Digital cameras or film cameras can generate materials in an incredibly large amount of data. Both in film cameras and digital cameras of higher classes you can film or photograph in the so-called RAW formats, but we also have options of various formats where image compression is used.
- The primary form of compression in many cameras is color sampling.
- This technology samples the luminance at a different frequency than the chroma.

Image compression

- Due to the fact that the human visual system is more sensitive to information about brightness than color, we usually use 4: 2: 2 compression, where the first digit is the values in the luminance channel, and the other two digits correspond to the sampling values from the chromium channels - this means that color channels are sampled in half as often as for luminance.

Other applications of Signal Processors

- Digital zoom.
- Preview your images on the LCD screen.
- Saving the image on the memory card.
- Applying color effects in real-time processing and in preview mode.
- And many others…