1 What contrast is and how to determine it

Content

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Definition

Every visual perception or photographic image begins with contrast, as it is only through its presence that objects come into existence for us. The following quotation illuminates this connection well:

"*Any object … can only be perceived by the eye ... if it stands out from its surroundings by a luminance different from that of the surroundings. Details in it are likewise to be recognized only if they differ from neighboring details in their luminance, so that corresponding differences in the illuminance on the retina or on the light-sensitive layer occur. Contrast is used as a measure of such differences. It is generally defined as the ratio between the luminance of the surrounding LU and that of the object LO.*" (1).

The term "contrast" is used in many different contexts, and to avoid misunderstandings, we must first define what we are discussing here. Contrast, derived from the Latin words *contra* ("against") and *stare* ("to stand"), signifies the opposite of something. In terms of the visual system, it refers to intensity values and brightness values. This is because contrast perception transforms differences in physical intensity (such as incident illuminance in lux or retinal illuminance in trolands) into differences in perceived brightness, which is experienced as intensity. In photography, we are dealing with contrast reproduction. In analog photography, we refer to these quantities as exposure values and density values, while in digital recording systems, we refer to them as exposure values and data values (binary values).

Contrast is, therefore, always the difference between light and dark, and contrast capability characterizes the ability to process these differences. The contrast range is the difference between the smallest and largest luminance, brightness, or density. A high-contrast image is characterized by a large difference between black and white, while a low-contrast image is characterized by closely spaced brightness values, as can be seen clearly in Figures 1 and 2. The limited contrast capacity of many photographic materials, compared to our visual system, is responsible for most misunderstandings and subjectively unsatisfactory images.

Since phototechnics allows us to measure the difference between light and dark in various contexts, we first aim to distinguish these different types from one another. Firstly, we consider the two forms typically encountered physically. **Illumination contrast** refers to the difference between the highest and lowest intensity of illumination applied to the subject. **Object contrast** refers to the difference between the

Figure 1: Image low contrast

Figure 2: Image high contrast

brightest and darkest parts of an object (object brightness). It is caused by the differing reflective properties of various surfaces and is, therefore, independent of the illumination. Figure 3 illustrates the relationship between the quantities involved: illuminance, object brightness, and the resulting subject brightness.

The resulting types of contrast rank second. Subject contrast refers to the difference between the largest and smallest amounts of light emanating from a subject. It depends on the illumination and the subject's ability to reflect it. The exposure range refers to the difference between the maximum and minimum exposure that the subject's contrast causes on the film, and it remains consistent after accounting for the contrast reduction caused by stray light in the lens and camera body. The permissible exposure range is defined as the difference between the brightest and darkest parts of the subject in which details should still be recognizable in the image. Apologies for the detailed distinctions and terminology, but this precision is necessary to ensure clarity when examining the contrast behavior of different image carriers in the following discussion.

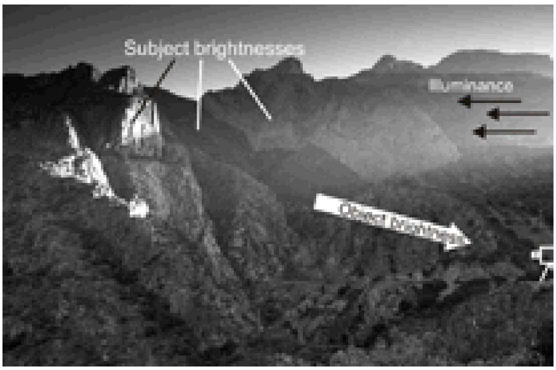

Figure 3: Types of contrast

To describe the contrast metrologically, one uses the contrast ratio between the luminance of the brightest and the darkest point. For the brightness values of natural scenes or images, the contrast ratio is defined as

Contrast ratio = maximum brightness / minimum brightness

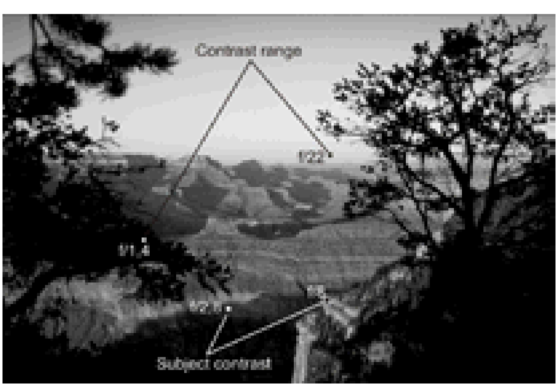

Figure 4: Subject contrast and exposure range. The aperture values are given for 1/250 sec

The logarithm

Before delving into the content, I would like to provide a brief explanation of a term that may not be immediately clear to everyone, yet it permeates the entire material: the logarithm. The term "logarithm" stems from the ancient Greek words λόγος (*lógos*), meaning "understanding, teaching, *ratio*," and ἀριθμός (*arithmós*), meaning "number." The logarithm is thus a "ratio number." It is one of the elementary mathematical functions.

....in mathematics

The formula symbol for the logarithm is "log." The base is indicated as a subscript. In rare cases, alternative notations such as "bloga" may be used, or the base may be omitted if it is clear from the context and there is no risk of confusion. One writes:

$$a = b^x$$

and says: "x is the logarithm of a to the base b," or alternatively, "x is the logarithm to the base b of a." The number a is called the numerus. The result of the logarithm reveals the exponent x needed to raise the base b to obtain the numerus a. Formally, logarithms are the solutions to the equation to given quantities a and b.

$$x = \log_b a$$

Depending on the number range and for which quantities this equation is considered, it has no, several, or exactly one solution. For example, 3 is the (real) logarithm of 8 to the base 2, written log2 8 = 3, because it is 23 = 8. If the above equation is to be solved to b instead of x, the solution is given by the x-th root of a. The following types and notations of the logarithm occur:

$\log_b$ Logarithm to base b

In Logarithmus naturalis, or natural logarithm, the logarithm to base e, Euler's number 2.7182818284590452...

lg The logarithm decadic, also known as the logarithm of ten or Briggs logarithm, represents the logarithm to base 10. It is useful because of the decimal system and is used by many calculators

ld Logarithmus dualis, logarithm to base 2, also called the two logarithm or dyadic or binary logarithm (sometimes abbreviated); used in computer science because of the binary system

log When the context clearly indicates it or a convention specifies it, we use the symbol log without a specified base. In technical applications (e.g., on most pocket calculators), log usually stands for the decadic logarithm; in computer science for the dyadic logarithm. Mathematicians and physicists usually use log for the natural logarithm. Occasionally, mathematicians and physicists also use log when the base is not significant.

...in photography

In photography, logarithmic relationships are ubiquitous. The f-stops on lenses, the exposure times on cameras, and the sensitivity values of films or digital image sensors are all based on a logarithmic system. Changing a lens by one full f-stop or adjusting a camera's exposure time by one full step allows twice or half the amount of light to reach the photosensitive layer. Similarly, increasing the DIN value of a film by 3 or doubling its ASA number also results in a doubling or halving of the effective light intensity. This is due to the fact that logarithmic relationships reflect a fundamental property of our visual perception (see "The Minimum Size of Brightness Differences"). Human perception, like many other sensory processes, is not linear but logarithmic in nature. This is highly advantageous for covering a wide range of intensities with limited perceptual capacity. In other words, we perceive one stimulus as stronger than another only if it differs by a certain factor. If our perceptual system operated linearly rather than logarithmically in many areas, a doubling of intensity would, for instance, be perceived as twice as bright, potentially causing permanent blindness in the presence of intense light on a sunny day. Comparing a linear scale to a logarithmic scale clearly illustrates this difference. The significance of the logarithm is perhaps most evident in this context.

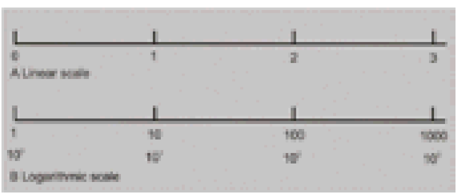

Figure 5: Linear and logarithmic scales

The upper scale in fig. 5 is constructed as an arithmetic series, meaning each step is equidistant from the next. In this series, each step increases by a constant value of one, resulting in a linear progression. The lower scale in fig. 5 is constructed as a geometric series, meaning each step is separated from the next by a constant multiplicative factor. Here, the markings differ by a factor of 10, resulting in a logarithmic progression. Consequently, the second step represents a value ten times greater than the first, the third step represents a value ten times greater than the second, and so on. These values are expressed as powers of ten, with equal steps in the exponent between 10^1 and 10^3. The logarithm provides a means of expressing these values. The logarithm of a number y, denoted as log y, is defined as follows:

$$\log_y = x \text{ means } 10^x = y$$

The logarithm of the markings in fig. 5 is therefore $\log_{10} 10 = 1$, because $10^1 = 10$, $\log_{10} 100 = 2$, because $10^2 = 100$, and so on. Thus, the markings correspond to equal steps on a logarithmic scale. In practice, such representations are used when it is necessary to clearly present wide gradations.

When describing photographic materials, we typically use logarithms with base 10. The conversion of $\log_{10}$ units into exposure steps is as follows: One exposure step corresponds to doubling or halving the amount of light, and the logarithm to base 10 of 2 is approximately 0.3 (since $10^{0.3} \approx 2$). Thus, for a dynamic range of 3.3 $\log_{10}$ units, $3.3 \div 0.3 = 11$ exposure steps.

The characteristic curve

The appropriate tool for assessing the contrast behavior of the visual system and photographic image carriers is the **characteristic curve**. In the field of photography, it is also known as the density curve or, after the founders of modern sensitometry, the **Hurter-Driffield curve** (H-D curve). Ferdinand Hurter and Vero Charles Driffield were the first to study the behavior of light-sensitive materials in the 1870s.

The characteristic curve plots the amount of light on the x-axis in logarithmic steps with base 10, while the resulting density (which is inherently logarithmic; see below) on the y-axis is represented linearly. Thus, the light intensity increases tenfold or decreases by a factor of 10 from one numerical value to the next, enabling a clear representation of a wide range of brightness without compressing the smaller range of stimulus responses or density values to a level that is too difficult to differentiate.

Figure 6 shows a typical characteristic curve. On the horizontal x-axis, we find the input quantity. In photography, this is typically the logarithm (base 10) of the exposure in lux-seconds (illuminance in lux multiplied by exposure time in seconds). These values are obtained by raising 10 to the power of the logarithmic numbers. For example, 0 corresponds to 10, because $10^0 = 1$, 1 corresponds to 100 ($10^1 = 100$), 2 corresponds to 1000 ($10^2 = 1000$), and so on. For negative exponents, which can also occur, the results are as follows: $10^{-1} = 0.1$, $10^{-2} = 0.01$, $10^{-3} = 0.001$. A step of 0.3 to the right on the x-axis represents a doubling of the light intensity, because $10^{0.3} \approx 2$. In perception experiments, the x-axis represents the logarithm of the intensity.

The numbers on the vertical y-axis represent the output quantity corresponding to the input value. In photography, this is the density of the image carrier. Density is a measure of the film's opacity, which increases when less light passes through. To determine density, light is passed through the negative, and the amount of light before and after transmission is measured. Opacity is the ratio of the incident light to the transmitted light. For example, if a negative transmits 1/100th of the incident light, the opacity is 100, because the incident light is 100 times the transmitted light. Density is the base-10 logarithm of opacity. A density value of 2 means the film transmits 1/100th of the incident light, because the opacity is 100 and $\log_{10} 100 = 2$. A density value of 3 indicates a relatively dark negative, as it transmits only 1/10,000th of the incident light ($10^3 = 10{,}000$). In the context of the visual system, the y-axis represents the receptor response as a relative stimulus response.

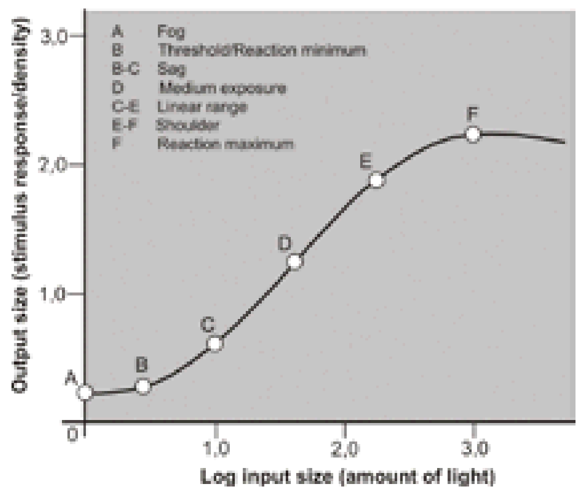

Figure 6: General characteristic curve