

Contrast ratio—what does it really mean?



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Introduction

Contrast, along with brightness, size, and "resolution" (pixel format), is certainly among the most widely-advertised of display specifications. But it's also among the least-understood. The others are pretty obvious—size can easily be seen and measured, and you can always (if you want to take the time!) count the number of pixels on the screen. Very few people who are shopping for a new display, though, actually understand what the "contrast" number means, and its importance in determining the quality of the display—other than perhaps a vague notion that a bigger contrast number is "always" better (isn't it?).

The basic idea behind the contrast specification (or, more correctly, the contrast ratio) is actually pretty straightforward. Simply put, it is a measure of the difference (in terms of brightness, or luminance) between "white" and "black" as shown on that particular display. This difference is expressed as a ratio—the "white" brightness divided by the "black," and usually expressed as a ratio of some number to one.

For example, if a display claims a contrast ratio of "500:1," what this is saying is that the white areas (the brightness when the video inputs are at their maximum value) are 500 times the brightness of the "black" (all video inputs at their minimum). Clearly, the more distinguishable "white" and "black" are (at least up to a point), the easier it will be to, say, read text on that display. If you don't think so, just try to imagine reading something printed in light gray text on a slightly-darker-gray background.

Put another way, low-contrast displays appear to be "washed out." Contrast also affects our perception of display brightness—most viewers will often report that a higher-contrast display is "brighter" than an identical but lower-contrast display, even if the two are adjusted so that the white levels are in fact exactly the same. This happens in large part because our eyes do not really "measure" brightness in an absolute sense—we generally perceive brightness only in relation to other objects in our field of view. An example of this is the image below:

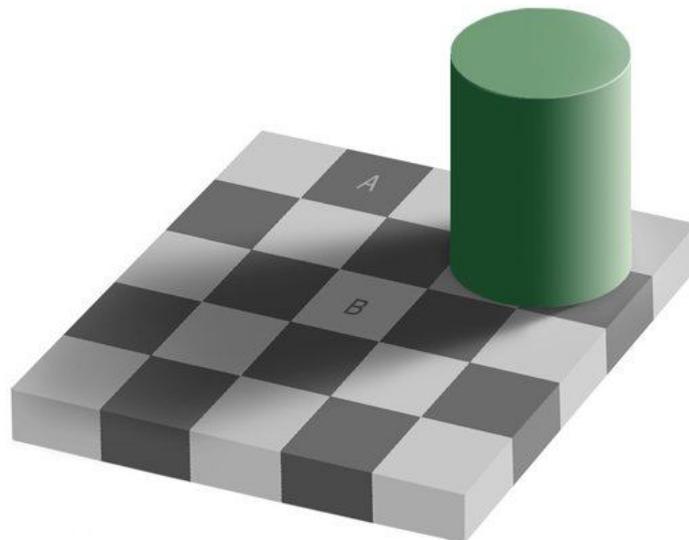
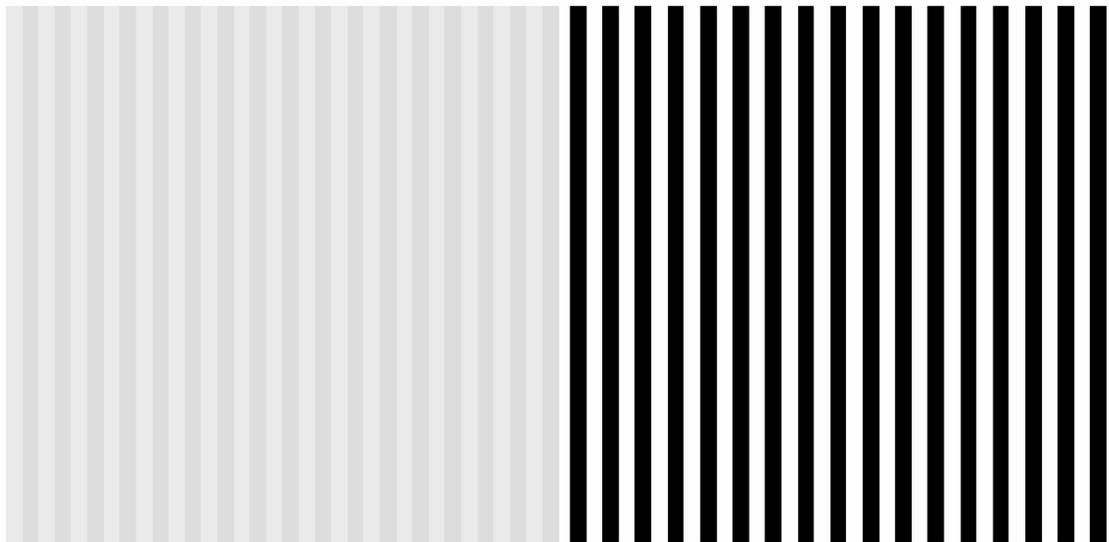


Figure 1. Demonstration of brightness perception

The square labeled "A" looks dark, while the one in the shadow labeled "B" looks lighter—but in reality, these two squares are actually the same shade of gray (you can cover up the rest of the image to prove this). We see square "B" as lighter only because it is surrounded by darker areas than "A" is.

Contrast also affects our ability to see details in an image; we can see much finer detail if the difference between the light and dark areas is more pronounced. Look at the two square patches shown below. Both contain the same number and size of lines, but the one on the right has much higher contrast than the one on the left. Now, start to move away from the page, and you'll notice that the left-hand patch appears to be just a solid gray area long before the right-hand lines become indistinct.

Figure 2: Demonstration of perception of light vs. dark



So from this, we should conclude that a high contrast ratio is a good thing, and the higher the better—right?

High contrast vs. low contrast

Well, not completely. As with most things relating to display specifications, the situation is a little more complicated than it may first appear. There are at least two other factors to consider: how much contrast we can actually distinguish (how big the difference between "white" and "black" needs to be before we simply can't see a difference any more), and how much contrast we can realistically expect the display to deliver in actual use.

The first question has to do again with how our eyes see differences between "bright" and "dark." As mentioned earlier, we don't really perceive brightness in absolute terms—what we're actually seeing are brightness differences. Beyond a certain point, increasing the brightness of an area won't make it look any brighter—our eyes are already seeing it as a very bright (possibly unbearably bright) area, and won't be able to tell the difference if it gets brighter. A similar situation occurs at the other end of the range—beyond a certain point, dark areas (at least "dark" as seen in relation to their surroundings) all look "black," and differences in their actual brightness cannot be seen by the eye.

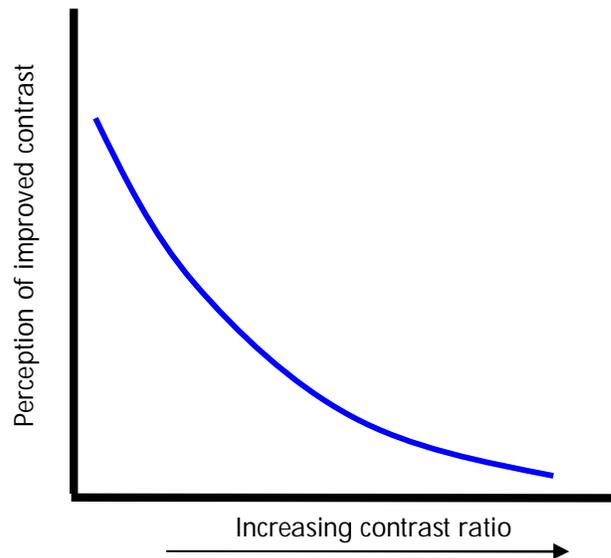
It's true that we can see in various light levels, over a fairly large range—your eyes work well in bright sunlight, but also in fairly dimly lit rooms. In each case, though, the eye must first adapt to the average light level of the environment before you can really see well. Everyone is familiar with this—if you come into a dark room immediately after being outdoors in the bright sunlight, everything looks black for a short time. Then, as your eyes adapt to the reduced light level, you again can distinguish different shades of gray, and soon you're seeing as well as before despite being in a much darker environment. The same thing happens in reverse when you step back outside—for a brief time, you're effectively blinded by the bright light—all you see is a bright scene, with little discernable detail. Give your eyes some time to re-adjust, though, and you can see normally again.

At any given moment, then—or, in terms of what our eyes are doing, for a given state of adaptation—we can distinguish brightness over a range of a few hundred to one up to perhaps 1,000:1 or slightly more (the exact number varies with the conditions and, of course, with the individual). In other words, if you can determine the maximum brightness that will be seen as "black," then a light source whose brightness is 1,000 times that of the "black" area will be seen as a bright white—and you won't be able to distinguish brightness changes above that. You also won't be able to distinguish "blacks" below that maximum "black" level—all will appear equally dark. You will only be able to distinguish "grays" between these two points. This says that beyond a certain point, increasing the contrast provided by a display won't make any difference—we won't be able to see it.

Certainly once you get past contrast ratios of about 1,000:1 or so, there's little benefit to trying for more contrast. The effect of increasing contrast is also very non-linear, since our eyes' response is not linear in the first place. You will perceive a change in contrast ratio from, say, 10:1 to 20:1 as very apparent; a change from 100:1 to 200:1 is definitely visible, but doesn't seem to be as much as the first change. And going from 500:1 to 1,000:1 is seen as a relatively minor change compared to the first two.

Figure 3: Perception of contrast ratio based on numbers

As the numeric contrast ratio increases, the *perception* of continued contrast improvement declines. Somewhere above a 1,000:1 or so, further improvements in the absolute, numeric ratio will be virtually unperceivable to the average viewer under any conditions.



So why do so many displays claim contrast ratios far greater than this? Advertisements touting contrast ratios of 2,000:1, 3,000:1 or even 5,000:1 aren't hard to find—look at almost any newspaper ad for high-definition TVs. Are they wrong?

The simple answer is no, they're not exactly wrong—these displays really do provide that much contrast, if you measure it in the usual way. The number specified, in most cases, is actually what's called the "dark room" contrast ratio—in other words, it's the ratio of white-to-black brightness if you're only measuring the light produced by the display itself. You measure the white and black in a room with absolutely no other light sources, and this is what you get. And while that is certainly one valid way to measure a display's contrast ratio, it doesn't really translate to what you'll see in actual use. How many of us use our monitors or TV sets in a room with absolutely no other light?

When there are other sources of light in addition to the display itself, there is another factor at work which determines the contrast you'll actually see in the displayed image. As we've noted already, contrast ratio is defined as the "white" brightness divided by the "black" brightness. However, with other sources of light in the room, the display screen itself is also lit from outside—light from the rest of the room is reflected by the display screen's surface and by the structures inside the display panel.

This can significantly reduce the contrast ratio as seen by the viewer. For example, let's say that we have a display with a "dark room" contrast of 500:1—which results from the display producing 250 cd/m² ("candelas per square meter," the standard unit for luminance) in the white areas, but only 0.5 cd/m² when black. If there is reflected light from the screen, which amounts to an addition of just 5 cd/m², then the contrast ratio would change to:

$$\text{White luminance/Black luminance} = (250 + 5)/(0.5 + 5) = 255/5.5 = 46.4:1$$

In this case, the effective contrast as seen by the viewer has dropped to less than a tenth of the specified value! And this is by no means an extreme example—in fact, it is very rare for any display to deliver much more than an effective contrast ratio of 100-200:1 in typical home or office lighting conditions. There are steps that can be taken in the design of the display to improve the contrast under typical conditions—for example, the addition of black materials surrounding the active pixel structures to cut down on the light reflected there, or treatment of the screen glass for the same purpose. No matter what is done, though, there's still going to be light reflected by the display screen, and the contrast will be reduced from its "dark room" value.

Dynamic contrast ratio

A new development in contrast ratio for LCDs is "dynamic contrast ratio," or DCR, which has a value significantly greater than the "static" contrast ratios encountered in traditional LCD monitors. DCR adjusts for dark and light images, enabling the display to present darker blacks onscreen. DCR can achieve a value in the 5000:1 to 10000:1 range and is desirable for home use, where displays are used for gaming and movies; it is also a marketed feature of high-definition televisions.

The way a DCR system works is to look at the average, overall brightness for a given scene, and adjust the backlight level to match. For instance, if you are watching a movie on the display equipped with DCR, and you come to a "dark and stormy night" sort of scene, the backlight level could be turned down considerably from what it would be when a brightly-lit scene is displayed. This makes the dark areas of such a scene even darker than they would be with the backlight fixed at its peak level. But in bright scenes, the backlight returns to its full level, making for the usual bright whites. If you compare the brightest whites (from the bright scenes) to the darkest blacks (as seen in the dark scenes), you can come up with a "dynamic contrast ratio" number which may be several times higher than what you would see comparing the peak white and minimum black within a single image (the usual "static" or "simultaneous" contrast ratio that we've been speaking of up until now). However, note that this means you can't really see this "DCR" contrast number in any single image—it's a comparison of a white level and the black level measured from two different images, at two different times. It tells you the range of black to white that the display is capable of over all time, not what you will see at any given moment.

DCR is not necessarily appropriate technology for mainstream office use, where traditional static contrast ratios in the 1000:1 and lower range yield the crisp clarity in details that is essential to accurately display office productivity and niche-specific business software. However, if business users are working with or developing multimedia content, DCR may be a beneficial display technology in that it will provide a viewing experience similar to what will be seen on many consumer televisions. Professional graphics artists, however, should be aware that DCR functions often alter the tone response (“gamma”) characteristics of the display and the video signal “on the fly,” and so what appears on the screen, while more “attractive” to many viewers, may not be an accurate representation of the image data. DCR should therefore be disabled in most color-critical applications in which an accurate representation of the source image data is of primary importance.

Conclusion

So what's the bottom line regarding contrast? It remains a very important specification regarding the performance of any display, but it should also be clear now that it's never just a case of "bigger numbers are always better." Major points to keep in mind:

- The actual contrast as seen by the viewer, under typical lighting in the home or office, will almost always be significantly less than the "dark room" value given in the specifications.
- A higher contrast ratio is better than a lower one, but the higher the contrast is, the less perceivable difference an additional increase will make—and there will come a point at which no continued increase (in absolute, objective terms) will be perceived by the viewer at all.
- As is usually the case in comparing displays, the final decision should be based on how they look to you, as viewed under the same conditions and with the same sorts of images you'll typically be using. In other words, the specifications can certainly be an important factor in your purchasing decision, but they shouldn't be all you consider.

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