Spurious resolution

Lens resolution is often expressed in terms of line pairs per millimeter [1]. The criterion used to determine whether the lines of a test chart are resolved can involve an objective measurement of contrast in the recorded image. Another criterion is subjective and involves an observer who visually distinguishes dark and bright lines in the image. Either way, the researcher should be aware of the possibility of spurious resolution. Spurious resolution is not specifically related to lens aberrations and can occur with microscopic and macroscopic subjects.

Figure 1 shows a little figure in front of a test chart, photographed with a 100-mm macro lens used on a 35-mm camera. The scene is captured at four different lens apertures from f/22, via f/11 and f/8, up to f/5.6. With Gromit being in focus, the test chart is progressively defocused. The f/22 image renders the background in reasonable focus and reveals a pattern of horizontal stripes on the left side, complemented with a smaller pattern of just four vertical black stripes in the bottom right of the chart. The upper right-hand side consists of plain text. At f/11 the background blur has increased, reducing the contrast between the dark and bright lines. The text is still legible. With a little imagination the writing is still readable at f/8, but the line pattern has degenerated into a nearly uniform gray blur. At f/5.6 one expects the background blur to increase even further. Indeed, the text is now blurred beyond recognition. Most surprisingly, however, there is an apparent restoration of the line pattern. The test chart at f/5.6, which should be—and factually is—defocused to a greater extent than at f/8, creates an impression of being resolved. A false impression, which is known as spurious resolution.

If you are adventurous, grab and print the background chart, and convince yourself.

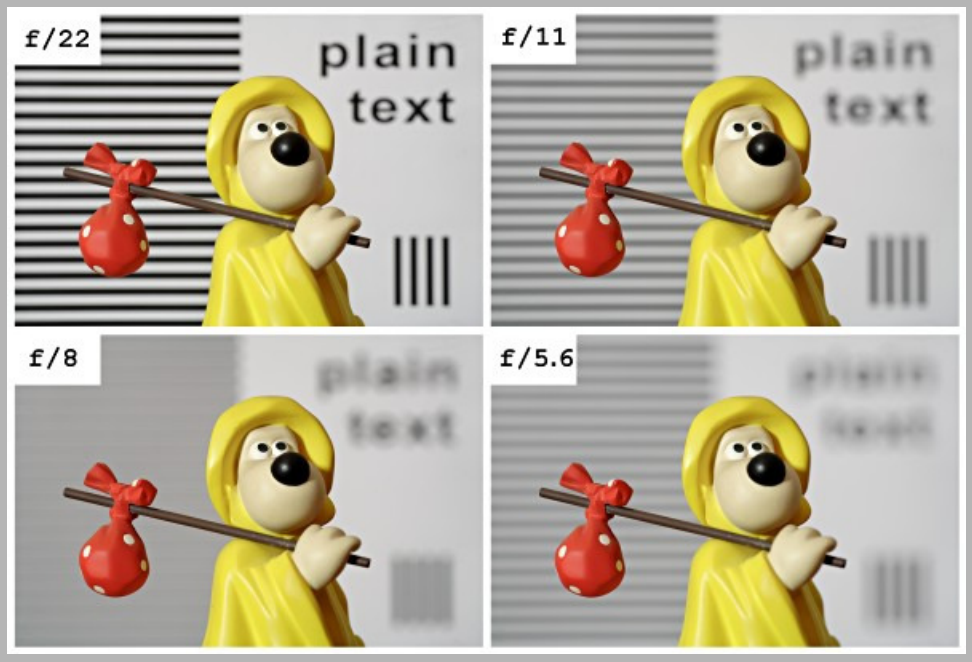

Figure 1. Gromit in front of a test chart, photographed at four different lens apertures. Spurious resolution occurs at f/5.6.

Upon closer examination of the f/5.6 photograph it is not just the reemergence of the line pattern that is curious, it is also subject to phase reversal. Dark lines have become the brighter ones and vice versa. Although mysterious at first sight, the occurrence of spurious resolution is readily explained by examining the influence of a uniform blur disk on the light intensity distribution across the image of a test chart. Figure 2 visualizes what happens when a pattern of four lines is defocused via a mathematical operation known as a convolution. Each point of the original target is spread out over a disk with diameter D.

For clarity, the figure only shows a one-dimensional cross section and uses different colors to discriminate the intensities of the individual bars. They are observed to broaden with an increasing blur disk diameter *D*. The graphs at the right show the total light intensity, which is simply the sum of the four separate curves at the left. The reduction in contrast at *D*=1.4, the uniform blur intensity at *D*=2.0, the reappearance of a line pattern at *D*=2.8 and its phase reversal, all observations of the photographs in Fig. 1 are reproduced. That includes the reduction of four bars to three spuriously resolved bars at *D*=2.8, which is in agreement with the bottom right-hand side pattern in Fig. 1. The target has four black lines, whereas the photograph at f/5.6 suggests that there are only three dark lines.

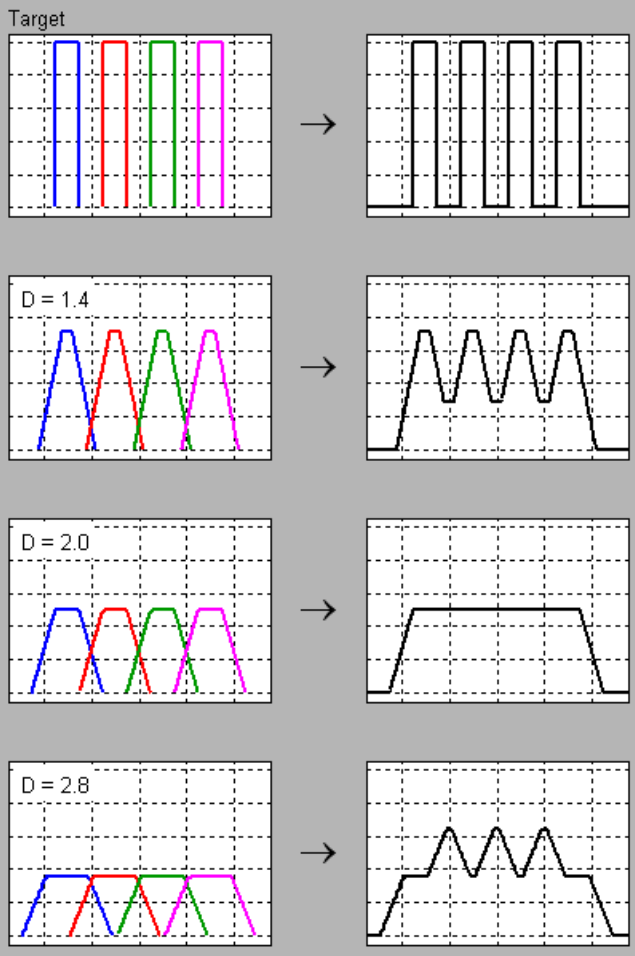

Figure 2. The effect of defocusing on a periodic structure of four bars. Left: individual elements are discriminated by the use of colors. Right: total intensity. The quantity D denotes the diameter of the blur disk (point spread function) in units of the bar width.

The effect known as spurious resolution is thus due to the broadening of individual elements which do not add up to a constant intensity, even when the defocusing exceeds the level at which these elements are normally no longer individually recognizable. Normally, in the sense that an aperiodic pattern is blurred beyond recognition. Spurious resolution is not restricted to line patterns, but can occur with *any periodic* structure. The reduction of *N* lines on a test chart to *N*–1 lines in an image is a strong, but not infallible [2] indicator of spurious resolution and a good reason to use charts with a few lines only. Few people will attempt to count the lines in the left-hand side of the photographs in Fig. 1, but a reduction from four to three lines is easily noticed. Phase reversal is also a sign of spurious resolution, but like line counting it is not infallible. Upon defocusing a periodic pattern spurious resolution manifests itself repeatedly, alternately with and without phase reversal.

Researchers examining the resolution of photographic lenses, human eyes [3], or whatever imaging system, should be aware of the possibility of spurious resolution. Unrecognized spurious resolution leads to a considerable overestimate of lens resolution or visual acuity. In subjective evaluations the traditional line pattern may be dropped altogether in favor of an aperiodic test chart, such as plain text at various font sizes.

References

[1] Norman Koren, http://www.imatest.com/docs/sharpness.html.

[2] R. N. Hotchkiss, F. E. Washer, and F. W. Rosberry, "Spurious resolution of photographic lenses," J. Opt. Soc. Am. **41**, 600-603 (1951).

[3] M. Bach, S. Waltenspiel, and A. Schilwächter, "Detection of defocused gratings - Spurious resolution, a pitfall in the determination of visual acuity based on preferential looking or VEP," in J. J. Kulikowski, C. M. Dickinson, and I. J. Murray (eds), *Seeing contour and colour*, Pergamon press, 562-565 (1989).

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