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Digital Image Improvement by Adding Noise: An Example by a Professional Photographer

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Abstract. *To overcome shortcomings of digital images or to reproduce traditional film grains, some photographers add noise to digital image. In an effort to find a factor of preferable noise, the authors analyzed how a professional photographer introduces noise into black-and-white images and found two characteristics: (1) There is more noise in midtones than in highlights and shadows and (2) histograms in highlights are skewed toward shadows, and vice versa, while almost symmetrical in midtones. The authors also found that by approximating the symmetrical histograms by a Gaussian distribution and skewed ones by a chi-squared distribution, the noise could be reproduced to an extent that well satisfies the professional. Comparison of professional's noise to film grain showed that they have the following in common: (1) more noise in midtones but almost none in brightest and darkest region and (2) asymmetrical histograms in highlights and shadows. The authors think that these characteristics might be candidates for "good" noise" that allows simulation of traditional film photography.* © *2011 Society for Imaging Science and Technology.*
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INTRODUCTION

Digital imaging technology has enabled us to acquire smooth and almost grain-free images. Even in this age of flourishing digital imagery, however, some people prefer and choose to use the conventional analog photographic process. One of the reasons is supposedly that the analog image is superior to a digital image in tonal quality. In fact, because current common digital image formats have only 8 bits (256 tone levels) in each channel, careless image processing sometimes leads to artifacts such as banding in smoothly transitioning areas or enhanced noise. Although raw data generated by digital single-lens cameras and advanced point-and-shoot cameras have more bit depth than what the JPEG format allows and have become a more common choice, not all photographers shoot only in raw format, presumably because of its large file size or required time and effort of postcapture processing to produce. A second reason may be the rich texture found in analog photographs.[1] It is said, ironically, that this richness is owing to the film grain, which has been thought to degrade image quality. In order to overcome such shortcomings of digital imagery or to simulate film grain for aesthetic purposes, some photographers attempt to add noise (grain) to the digital image in their workflow of image processing.[1–3]

Another form of "graining" of images is the application of film grain to video/movie images.[4–6] The aim of such research is to synthesize the original film grain that has been removed to improve the efficiency of encoding and transmission of the video signal and to restore the natural appearance of the video sequence.

Although numerous attempts have been devoted to removing digital camera noise or grain of silver halide film to improve image quality, there are some implications that noise in an image can have a positive effect on digital image quality. For example, Johnson and Fairchild asked human observers to evaluate the sharpness of photographic prints, changing various image quality attributes: resolution, sharpening, contrast, and noise.[7] They found that, as an interesting result, an appropriate amount of noise increased the perceived sharpness. In other work, they investigated adaptation to image noise, extending the concept of adaptation.[8] Noisy images on a noisy background were presented to human observers, and the elevation of the threshold for noise visibility was measured. They found an increase in observers' contrast detection threshold after adaptation and suggested that such adaptation to noise could enhance the salience of image content while minimizing the perception of artifacts. Kashibuchi et al. examined whether noise addition could improve the quality of digital photographic prints.[9] Observers were asked which of a series of black-and-white images with various noise levels was most preferable. They concluded that certain kinds of subjects were preferred when noise was introduced, and the effect was mainly the enhancement of subjects' texture. We think that this is one example of enhancement of image content by noise suggested by Fairchild and Johnson.[8]

Even though it is of interest to find a parameter of noise that gives a favorable effect or improves image quality, it is difficult to determine such a parameter from literally innumerable combinations of noise attributes—level, histogram, power spectrum, or chromatic/luminance. Thus, in this article, we refer to the way a professional photographer, who is generally thought to create good imagery, introduces noise to a digital image. We think that trying to characterize such noise will provide another strategy to deal with noise in digital imagery.

We first analyze how the professional photographer

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Figure 1. Some examples of images created by Kunitoshi Yabe, a professional photographer. Subjects include portrait (left four images), landscape (middle), and still life (right). (Images are courtesy of Kunitoshi Yabe.)

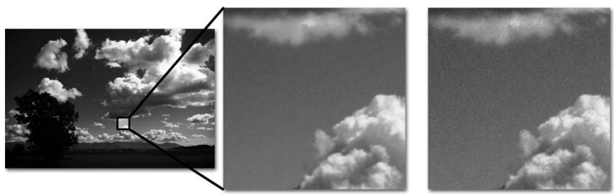

Figure 2. A Landscape image (left) and magnified view of its portion without Yabe's noise (middle) and that with the noise (right).

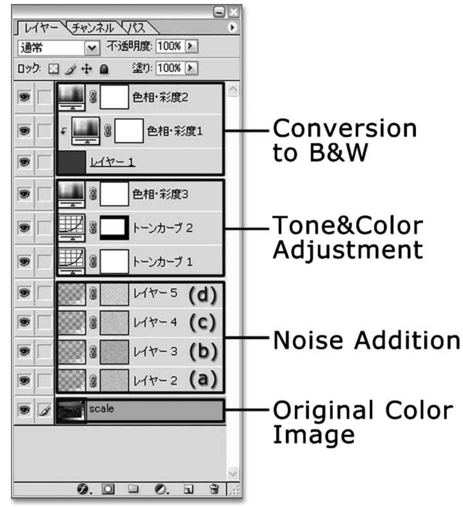

Figure 3. A typical example of layer arrangement in the photoshop files. The layer at the bottom is an original color image. The four layers on top of it add and control noise. Top three layers convert the color image into black and white. Remaining layers control tone and color.

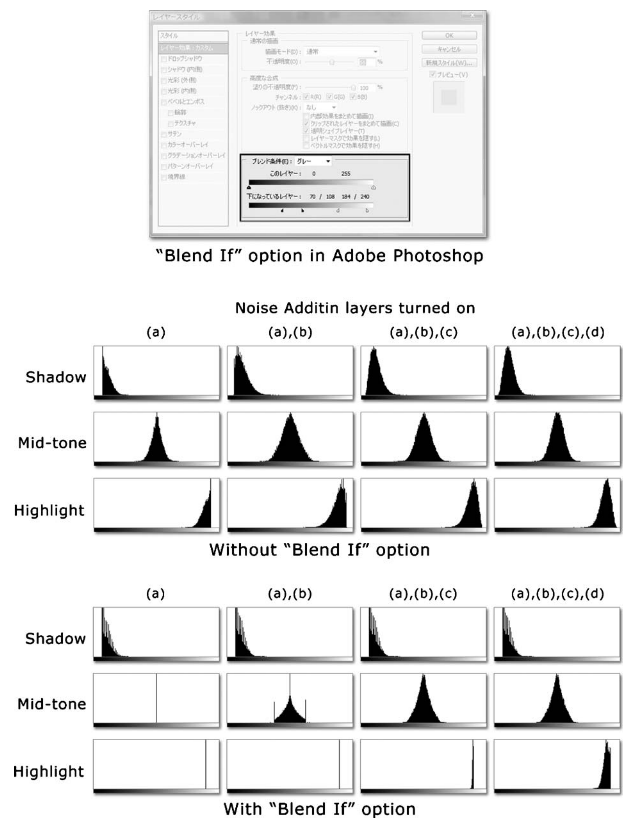

Figure 4. Blend If option of photoshop (top) and its effect on noise characteristics. Although leaving Blend If option default applies noise to the entire tonal range (middle), Yabe can change this option to achieve the desired effect (bottom).

adds noise to digital images, and next examine whether this noise can be reproduced in order to make sure that the characteristics found in the analysis is the essence of professional's noise. The professional photographer's noise is compared to the grain of traditional black-and-white silver halide prints.

ANALYSIS OF PROFESSIONAL'S NOISE

Method

A total of 36 black-and-white images, whose subjects included portrait, landscape, and still life, were created by Kunitoshi Yabe, a professional photographer, who is also an image editing expert and deals with other photographers' work. Some examples of his photographs are displayed in Figure 1. All the images were provided as Adobe Photoshop files whose color space is Adobe RGB with 8 bits/channel. The image size ranged from 4.1 to 6.8 Mpixels and was 6.2 Mpixels on average.

To demonstrate the effect of the noise, enlarged portions of a landscape image (08.psd) without noise and one with noise are shown in Figure 2. After noise addition, the banding and digital camera noise in the sky became less noticeable due to the masking nature of the noise. Using the same landscape image as in Fig. 2, Yabe argued, in a book in which he explains how to use photoshop skills (not limited to noise addition) to improve digital images, that adding noise could restore details in blown highlights and improve the perceived (not physical) resolution.[10] He also claimed that this technique was beneficial for reducing JPEG-compression artifacts and blur due to interpolation, especially in the case of a relatively small (file size) image.

Figure 3 is a typical example of layer arrangement in the photoshop files. The layer at the bottom of the stack is the original image (in color). Color noise is applied to the original in the next four layers; this added noise is the main focus of our study. By altering the opacity and "Blend If" options of the layers (top of Figure 4), the professional photographer adjusts the noise. Three layers on top of the layer stack control the hue, saturation, lightness, or tone of the image. In addition, some images have layers that locally alter (dodge or

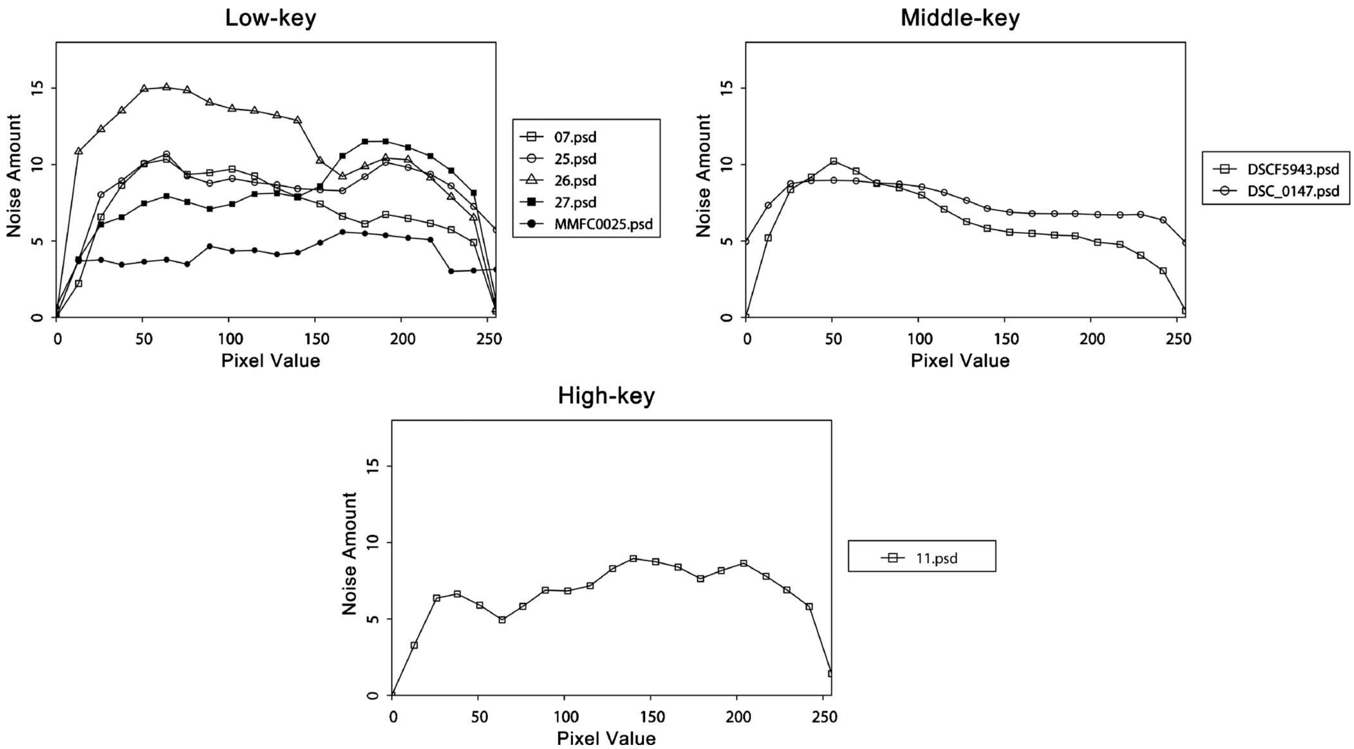

Figure 5. Measured amount of the noise for portrait images. Top left panel represents low-key images, top right represents middle-key images, and bottom represents high-key images.

burn) the image. Finally, the top three layers convert the color image into black and white, controlling the overall tonality of the image.

Interestingly, each of the four noise addition layers plays a somewhat different role. At the bottom right of Fig. 4 are the histograms measured from shadow, midtone, and highlight (from top to bottom row), with each of the four noise addition layers cumulatively turned on (from left to right). Whereas enabling noise addition layer (a) applies noise only to shadow areas, layer (b) mainly affects midtone, leaving noise in shadow area almost intact. Similarly, further turning on layer (c) adds noise to the highlights slightly, and layer (d) increases exclusively the highlight noise level. This effect can be realized by the control by Yabe of the Blend If options: While leaving the option default (untouched) applies noise to the entire tonal range (bottom left of Fig. 4) even when only layer (a) is enabled, altering it affects the histogram of the noise and the tonal range to which the noise is introduced (bottom right). In this way, he is leveraging the flexibility of digital image processing to achieve his goal.

To find a trend, we categorized the images according to subject (portrait, landscape, and still life). We also classified them into three categories according to the mean brightness of the whole image after black-and-white conversion. Tonal ranges of $R,G,B=0-255$ were divided into three equal intervals, and if the mean pixel value of an image, L, was in the darkest interval (i.e., $0 \leq L < 85$), the image was classified as a "low-key" image. Similarly, if $85 \leq L < 170$, the image was classified as a "middle-key" image and if $170 \leq L < 255$, it belonged to a "high-key" image. As a result, images were classified into a total of nine categories.

To characterize the noise, we made a grayscale image and asked Yabe to insert it into the original images. The gray scale consisted of 21 steps, which was 300×145 pixels in size and divided the tonal range of 0–255 into 20 almost equal intervals. The amount of noise, defined as the standard deviation of pixel values within each step, was measured from each channel of the gray scale with only the original image layer and noise addition layers turned on, i.e., the function of noise addition layers was investigated. Histograms of the noise were measured in the same way.

Results and Discussion

Figures 5–7 show the amount of noise measured for each subject. Each one is further classified according to the "key" of the image. As all channels had almost equal amount of noise, values for the G channel are shown here.

None of the graphs are completely flat, which means that the amount of noise depends on the pixel value of the pixel to which the noise is added. Although some curves look similar to each other, there is a variety in the shape of the curves, presumably because of image-dependent adjustment by Yabe. All the graphs, however, seem to have more noise in midtones than in highlights and shadows. Generally, in highlights (pixel value of 0–36) and shadows (207–255), the amount of noise gradually decreases toward the ends of the tonal range. Additionally, in most cases, the amount is almost zero at pixel values of 0 and 255.

Histograms are also dependent on pixel values. Figure 8 presents one representative example of the histograms measured from 21 steps of the gray scale in image 20.psd. The same as for the noise amount, the result for the G channel is

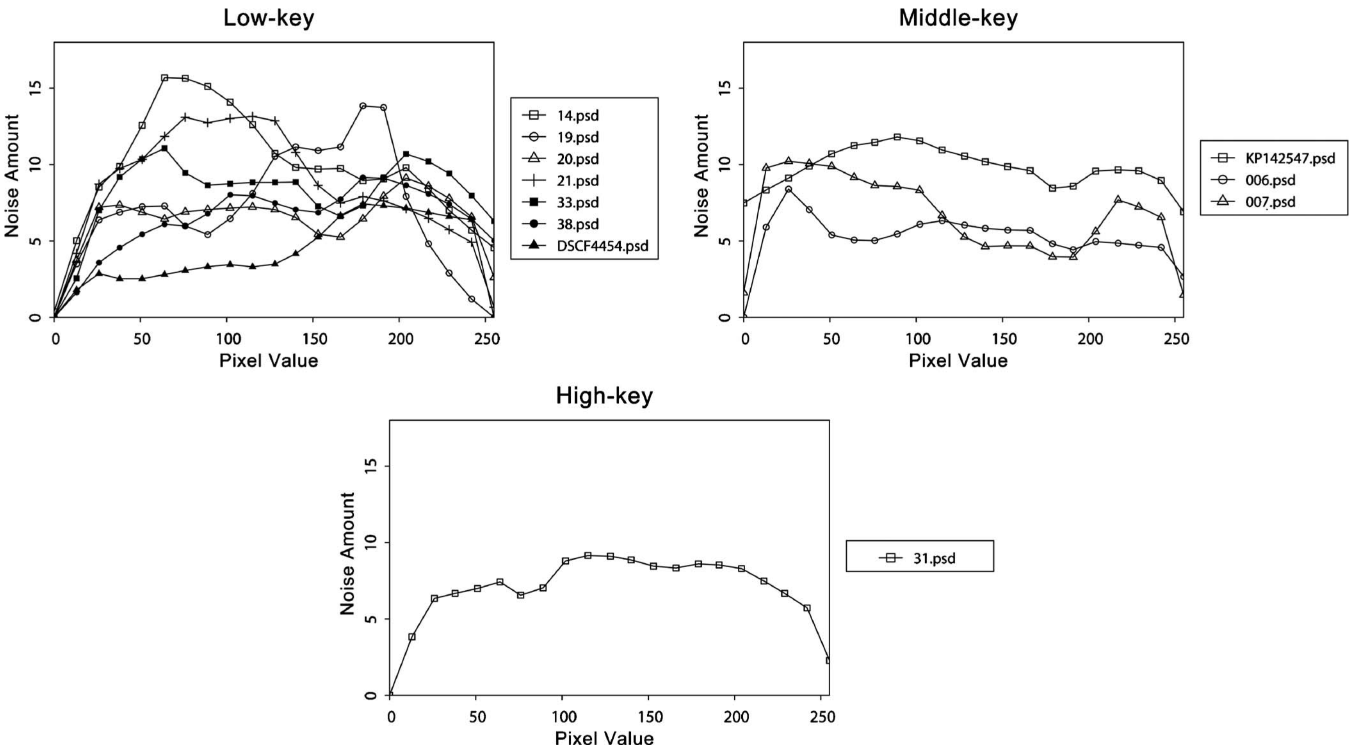

Figure 6. Measured amount of the noise for landscape images.

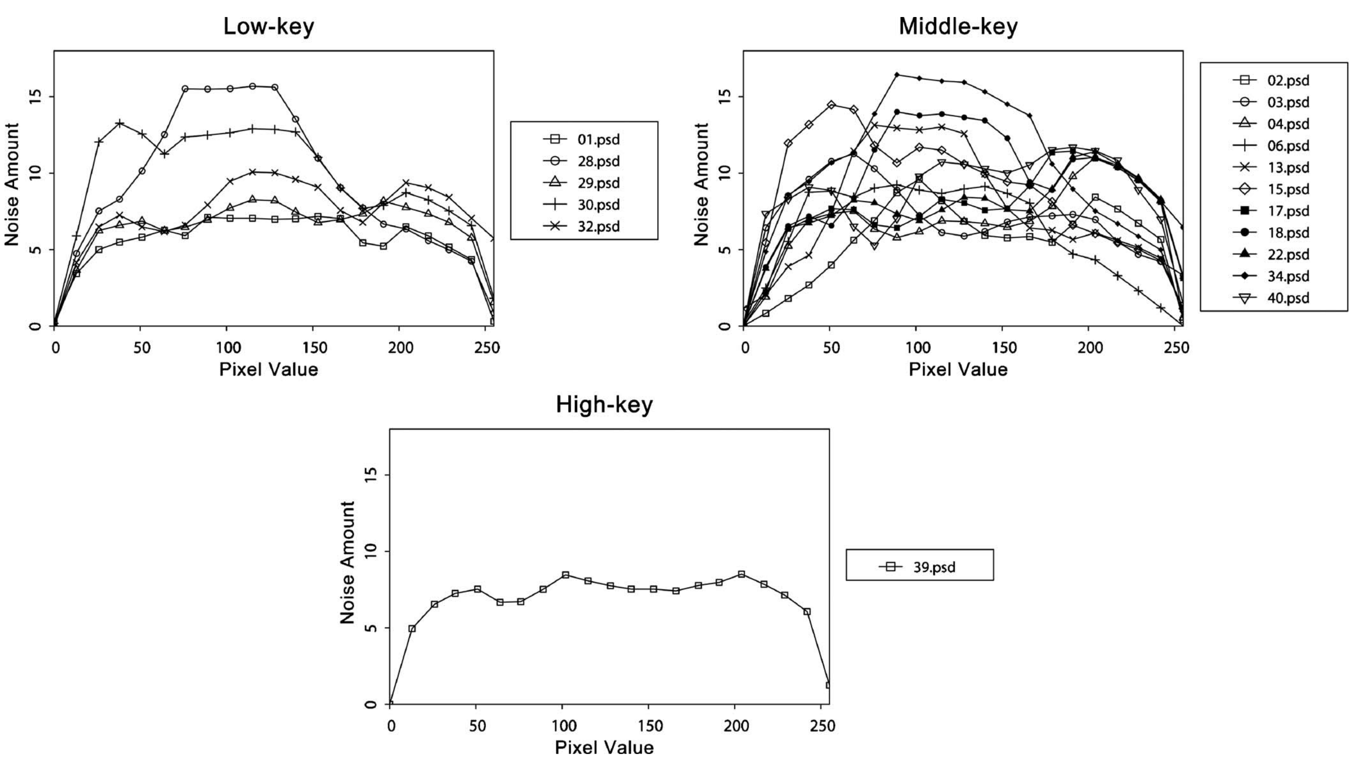

Figure 7. Measured amount of the noise for still life images.

shown here. Histograms corresponding to the midtones (middle seven and left three panels in the bottom row) have a sharp and almost symmetrical shape. In the shadow regions (top seven panels), on the other hand, they are skewed toward highlight levels and appear more skewed as the average pixel value gets smaller. Histograms corresponding to highlights, in the contrary, are skewed toward shadow levels (right four panels in the bottom row), and the skew become more obvious as the average pixel value becomes larger. This

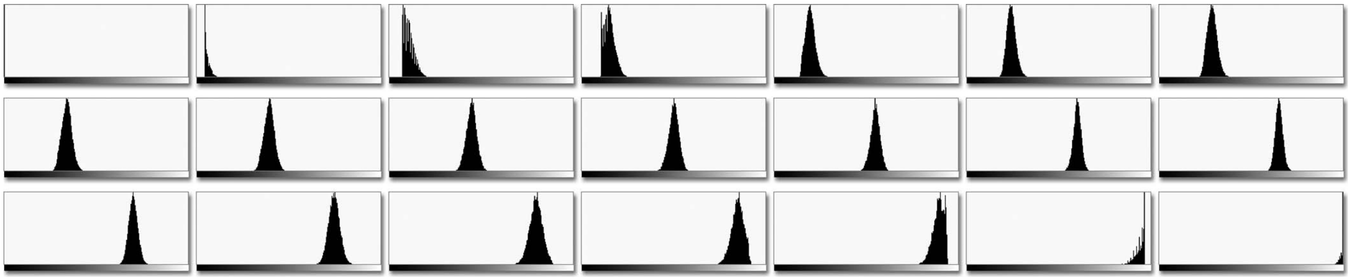

Figure 8. Histograms measured from 21 steps of the scale in an image (20.psd). They are almost symmetrical about their peaks in midtones. In highlights, they are skewed toward shadow, and vice versa.

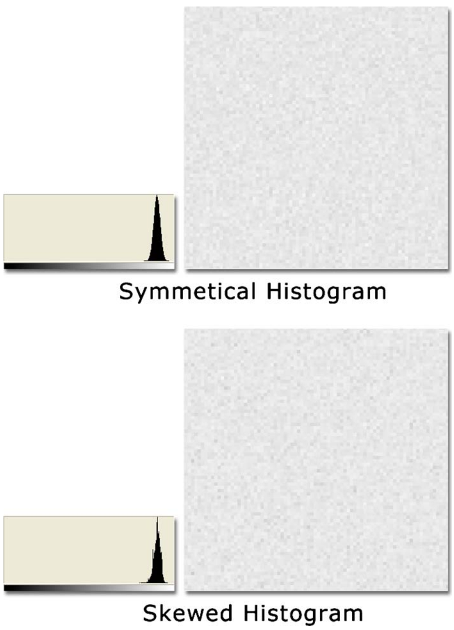

Figure 9. Difference in the appearance of noise due to difference in histogram. The upper image appears to have more dark pixels than the lower one, although both have the same noise amount and mean pixel value.

characteristic is common to all the images, although some histograms do not have smooth shapes.

Different appearances of noise owing to histogram difference are demonstrated in Figure 9. The noise in the image on the left has a symmetrical histogram (Gaussian distribution; shown in lower left), while the one on the right, cut from the third lightest step of the scale in Yabe's image (20.psd), has an asymmetrical histogram. Although both noise distributions have the same mean pixel value of about 230 and the same amount (standard deviation) of about 5.7, we see more dark pixels in the right image than in the left one. Similarly, when professional's noise, which also has an asymmetrical histogram, occurs in shadow regions and is compared with noise that has a symmetrical histogram, we will see more white pixels in professional's noise. The noise created by Yabe is obviously different from, for example, the noise obtained by applying the photoshop "Noise" command, whose amount and histogram are constant over the entire tonal range, independent of the gray level of the pixel to which the noise is added.

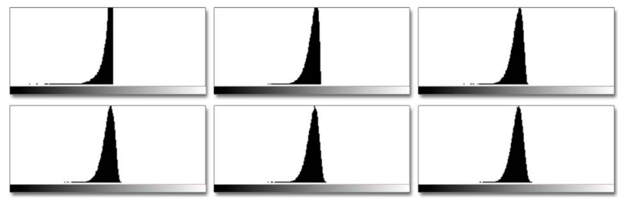

Figure 10. Chi-squared probability distributions with various DOFs. From top left to bottom right, DOF=1, 4, 7, 10, 13, and 16. The smaller the DOF, the more skewed the distribution.

REPRODUCTION OF PROFESSIONAL'S NOISE

To confirm that the characteristics described above are the essential features of Yabe's noise, we tried to simulate it. If we could, we think that it will contribute to the aesthetic aspect of photography and be a good starting point for photographers who want grains in their digital images.

Method

We tried to reproduce professional's noise or the function of noise addition layers described in the previous section. Noise was added to each pixel of the original color images as chromatic noise using a computer program. This program approximates a symmetrical histogram with a Gaussian distribution, which has a symmetrical bell shape. On the other hand, a skewed histogram is substituted by a chi-squared probability distribution, which is characterized by its asymmetrical shape. The degree of skew of the chi-squared distribution can be controlled by its degree of freedom (DOF), which is a natural number. Examples of histograms based on the chi-squared distribution are shown in Figure 10. As the DOF becomes larger, the histogram of the distribution appears less skewed. The amount of noise is controlled by changing standard deviation of the distribution.

The initial noise amount was set as the average value for each category. For the histogram shape, DOFs were visually determined for each image and the average values for each subject were used. Since the measured noise is almost equal in each channel, we used the same parameters for each of the R, G, and B channels.

The images to which the simulated noise had been added by the program were then inserted into each original photoshop file with only color/tone control and black-and-white conversion layers (Fig. 3) applied to convert to black and white. We presented the reproduced black-and-white

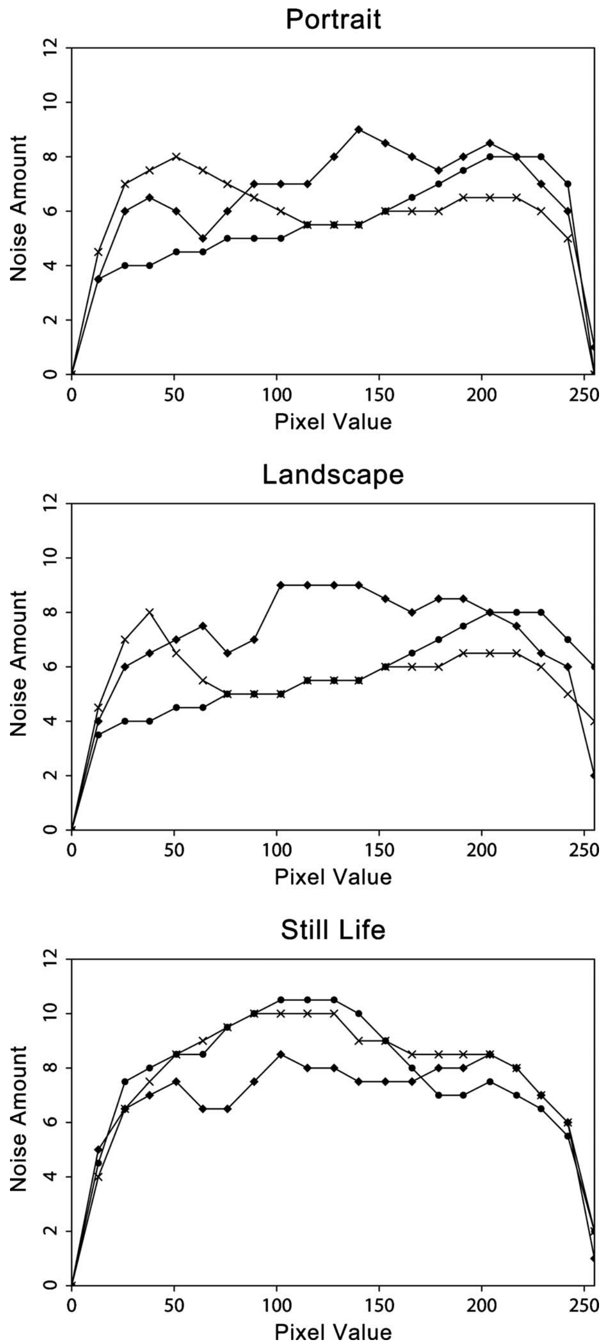

Figure 11. Parameters for the noise amount found to be satisfactory to the professional photographer. Top left panel represents portrait images, top right represents landscape images, and bottom represents still life images.

images to the professional, who served as an arbiter of the aesthetic quality of the images, and asked to score them on a scale of 1–100 points. If they were not satisfactory to him, the parameters were revised according to his advice and the process was repeated.

Results and Discussion

After a few iterations, we obtained parameters that were found to be satisfactory to Yabe. Figure 11 shows the result of noise amount, and Table I shows the histogram shape characteristics.

These parameters acquired 80–100 out of 100 points in Yabe's judging. Especially for 12 out of 17 still life images, the result was scored 100 points and the professional said that there were "no problems at all" in the simulated image. We think that this result gives photographers the possibility of automatically applying noise by classifying images according to subject and average brightness.

An interesting result is that when DOFs for the landscape image were substituted for those for the portrait image but the noise amount was kept constant, the score was much lower. This indicates that DOF, or histogram shape, also plays an important role in professional's noise. On the other hand, taking into consideration the fact that a variety of graphs of noise amount could be approximated by one for each category, we think that there is some latitude in the amount of noise. We also think that three curves for each subject category might be represented by one curve, thus resulting in one set of noise amount curves and DOFs for each subject.

COMPARISON OF PROFESSIONAL'S NOISE TO THE GRAIN OF ANALOG PHOTOGRAPHY

Method

Since Yabe said that he added noise to digital images so that "it looked like the grain of black-and-white silver halide photographs," we measured the characteristics of the grain of analog photograph and compared it to his noise in terms of the amount and histogram of noise. We photographed a gray cardboard with a black-and-white film (Kodak Tri-X), slightly defocusing so as not to capture its texture. Compensating for the exposure from −1.5 to +4.0 stops in 0.5 stop increments, we made 12 exposures. The film was developed in a Kodak HC-110 developer for 3 min and 45 s at 20 °C, which is one of the combinations recommended by the manufacturer. The developed film was then printed on a Fuji

Table I. Parameters for histogram shape found to be satisfactory to the professional photographer, Yabe; G in the table stands for Gaussian distribution and numbers stands for the DOF of chi-squared distribution. For pixel values not shown in this table, linearly interpolated and rounded values are used.

	Gray level of the pixel to which the noise was added													
Subject	0	13	26	38	51	64	76–166	179	191	204	217	229	242	255
Portrait	1	4	14	G	G	G	G	G	G	G	G	14	7	1
Landscape	1	3	6	10	14	G	G	14	12	10	7	4	2	1
Still life	1	2	4	6	10	14	G	G	G	G	10	6	2	1

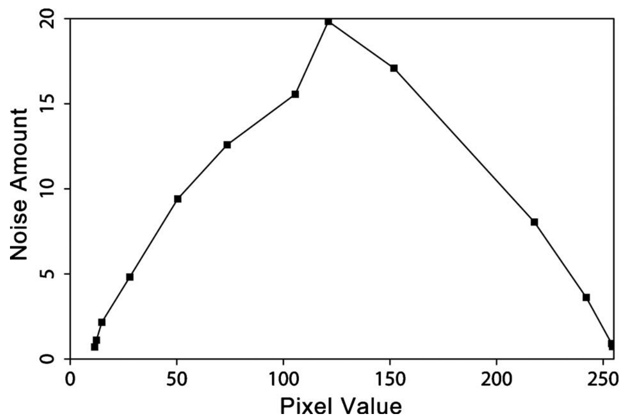

Figure 12. Amount of analog black-and-white print noise depends on the average pixel value and reaches the maximum at pixel value of 121 and gradually decreases toward the pixel values of 10 and 255.

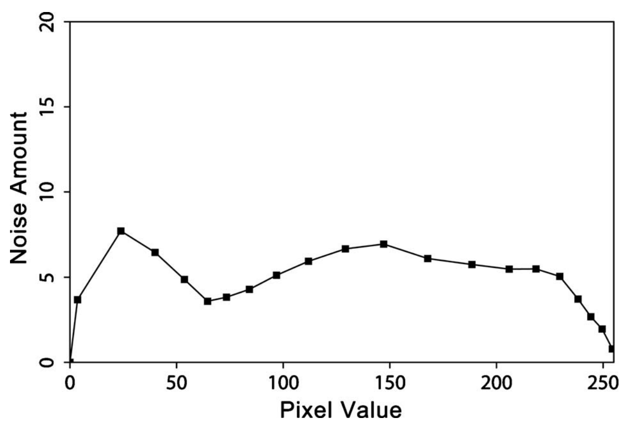

Figure 13. An example of the amount of professional's noise after black-and-white conversion (20.psd).

Fujibro™ WP FM3 paper with 12× magnification under constant exposure condition for all the shots. The paper was developed in an Ilford Multigrade Paper Developer for 1 min and 30 s at 20 °C, which is also a standard procedure.

The prints were then converted to digital data using a scanner (Canon CanoScan D1250U2) at 2400 dpi in grayscale mode with automatic functions turned off. After the conversion, the scanned images were converted to Adobe RGB color space and resized to $2000\times3000=6$ Mpixels using photoshop to make them comparable to professional's photographs. Finally, the amount of noise (again, defined as the standard deviation of pixel values) and histograms were measured from an area of 369×369 pixels. Since the noise measured in the analysis section was in color, the amount and histograms of Yabe's noise after the black-and-white conversion were measured for one of the images (20.psd) for comparison here.

Results and Discussion

Figure 12 plots the amount of noise obtained from the black-and-white prints against the average pixel value of the area. It is found that the granularity of analog black-and-white print depends on the average pixel value and has a simple mountain shape with a maximum value of 20. This corresponds to the fact that, when viewing a silver halide

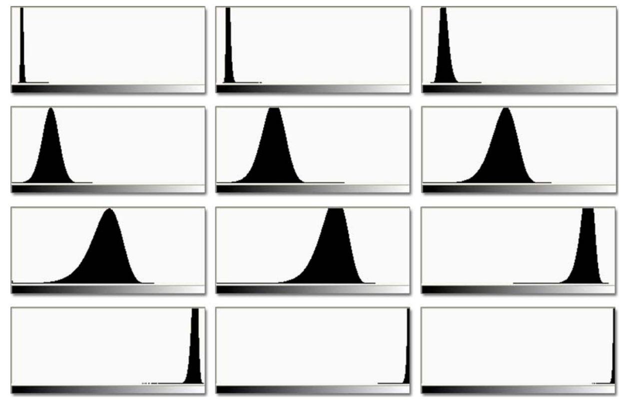

Figure 14. Histograms of analog black-and-white print noise. Two of them are almost symmetrical about the peaks (two images on the top right). In lighter region, the histograms are skewed toward shadow, while in darker region, they are skewed toward highlight.

black-and-white photograph, we see more grains in midtones than in highlights and shadows.

Figure 13 shows that the amount of professional's noise, even after the black-and-white conversion, depends on the value of pixel to which the noise is added. There is more noise in midtones, but the noise decreases to zero toward the pixel values of 0 and 255.

As the grain of an analog photograph depends on the choice of film, developer, and developing time, we cannot compare these two kinds of noise quantitatively. Qualitatively, however, two attributes can be found: (1) There is more noise in midtone than in highlights and shadows and (2) noise approaches zero in the brightest highlights and deepest shadows, gradually decreasing in highlight and shadow regions.

Figure 14 shows that the histograms obtained from the analog prints have both symmetrical and asymmetrical shapes. Two of the histograms in darker midtone (top right two images) have almost symmetrical shapes. On the other hand, the histograms corresponding to shadow are skewed toward highlight and those corresponding to highlight are skewed toward shadow.

Figure 15 shows Yabe's noise after the black-and-white conversion maintains symmetrical and skewed histograms and the direction of skew found in Fig. 8. Although the range with symmetrical histograms is different in the two kinds of noise, they have the following in common: (1) symmetric histograms in midtones and (2) direction of skewed histograms in highlight and shadow regions.

These results can be explained theoretically by the results of research on silver halide photographic materials.[11] The Siedentopf relationship states that the image noise level G, as measured by mean square fluctuation in density, is dependent on the image density and for monosized grains is linearly proportional to the image density.[11] The noise amount as measured by the standard deviation or root mean square of gray level thus is proportional to square root of image density. Noise measured from the analog photographic print (Fig. 12), however, does not appear to correspond to this expectation, which is attributed to the sigmoid

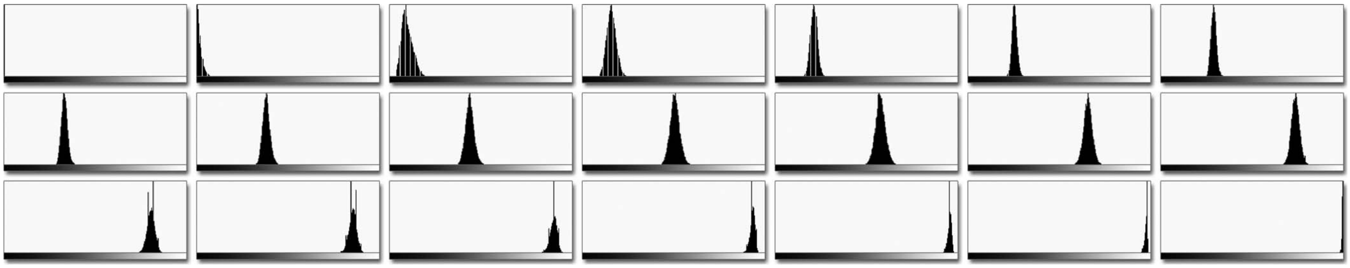

Figure 15. Histograms of Yabe's noise after black-and-white conversion for image 20.psd.

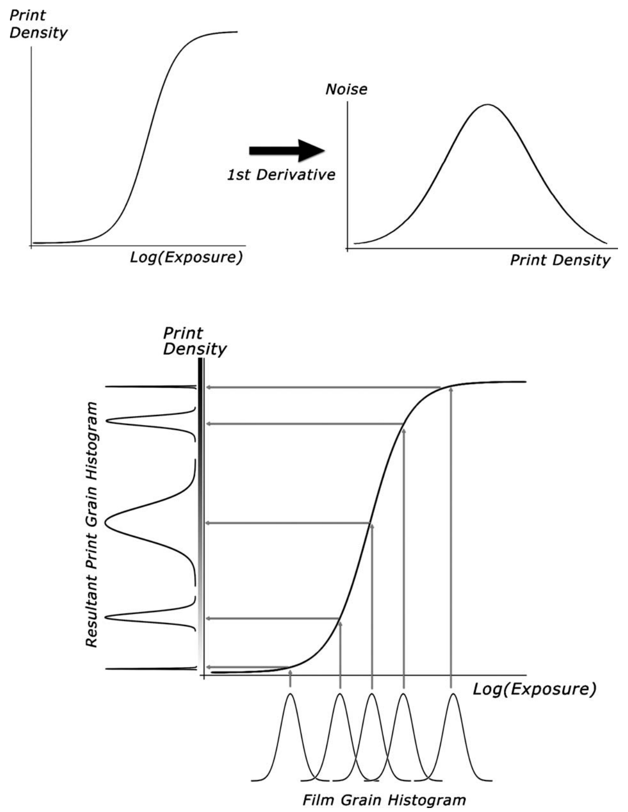

Figure 16. Schematic diagrams of film grain transfer to print noise. Film grain histogram is amplified by the slope of paper characteristic curve in midtone while severely compressed by the plateau of the curve in the highlight and shadow. The toe and shoulder of the curve skew the Gaussian-distribution-shaped film grain histogram (top). First derivative of paper characteristic curve gives the degree of the amplification, which corresponds to (relative) amount of noise (bottom).

nature of the paper's characteristic curve: The linear potion, which is the steepest in the curve and corresponds to midtone in the final print, amplifies noise, whereas the plateau compresses and greatly reduces the noise amount. The top panel of Figure 16 shows the slope, or the first derivative of paper characteristic curve, which also indicates the (relative) amount of final noise. The almost symmetrical mountain-shaped curve is in good agreement with the measured one (Fig. 12).

Dainty and Shaw showed that image fluctuation, or noise histogram, follows a Gaussian distribution.[11] Based on this result, we can explain the skewed/symmetrical histogram shape: Linear portion of the characteristic curve does not affect its symmetrical shape, while as the slope of nonlinear portion of the curve becomes milder, the histogram becomes more compressed (Fig. 16, bottom). As a consequence, print noise histograms in midtone have symmetrical shapes and histograms in highlight become skewed toward shadow, and vice versa.

CONCLUSIONS

We have examined image noise that Yabe, a professional photographer, adds to improve the quality of digital image and found two noteworthy characteristics: (1) There is more noise in midtone, while the noise decreases to nearly zero in highlight and shadow area; and (2) histograms are symmetric shaped in midtones, while in highlights, they are skewed toward shadow, and vice versa. To confirm that these are the essential characteristics of his noise, we tried to reproduce the noise on the original images and asked the professional to evaluate them. We first classified the images provided by Yabe into nine categories according to the subject and overall brightness of the image. By approximating the symmetrical histograms with a Gaussian distribution and the asymmetrical ones with a chi-squared distribution, and by setting parameters for each category, we could reproduce Yabe's noise to an extent he was well satisfied.

As Yabe said that he added noise so that it looked like the grain of gelatin silver prints, we compared experimentally the two types of noise in terms of the amount and histogram shape and found two common attributes: (1) more noise in midtone and less in highlight and shadow and (2) asymmetric histograms in highlights and shadows along with the direction of skew. This signal dependency of noise level and histogram shape is also confirmed from the results of silver halide photographic research.

Although qualitative, these are the attributes recognized by Yabe, a professional photographer, in the grain of silver halide photographs, which have been accepted widely and for a long time. We consider that these attributes are also what the professional anticipated would contribute to the quality improvement of a digital image, and therefore might be one condition of "good" or preferable noise from an aesthetic point of view.

ACKNOWLEDGMENTS

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