

Simulating Film Grain using the Noise-Power Spectrum

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Abstract

Film grain is an essential part of real images. The artifacts it introduces add character to images, which can otherwise appear too perfect. This paper considers the synthesis of film grain based upon its noise-power spectrum, producing grain fields which approximate real film over a range of enlargements and densities.

We also identify limitations of the noise-power spectrum in that it fails to fully characterize grain. Simulated grain fields have spectra which match real grain, but lack the phase and density correlations required to create the appearance of individual grains at high magnifications.

Categories and Subject Descriptors (according to ACM CCS): I.3.m [Computer Graphics]: Miscellaneous

There is increasing recognition that grain is a component of traditional film which needs to be specifically addressed within the digital imaging pipeline. Digital capture, and 3D rendering systems can create images which are grain free, but these can be visually less compelling than images with grain included. These may also be combined with images captured on film, which do contain grain, and therefore grain must be added to digital images.

Additionally film grain causes problems for the compression algorithms used in the distribution of digital video, as film grain is essentially high frequency noise which compresses poorly. To efficiently compress grainy images, the grain must first be removed. A reciprocal process during the decompression can then add artificial grain to the image prior to viewing [LBT07].

To create synthetic grain for these applications a number of approaches have been used. Real film grain can be scanned, and then combined with new images [GLC06], but this is limited by the size of the grain library available. [SCW06] uses real film grain as the basis of a grain re-synthesis system, allowing new grain to be generated to match existing grain patterns.

The most common technique is to treat grain as noise and filter it to produce a totally synthetic grain field [LBT07] [GM97]. However this filtering is typically performed in an ad-hoc fashion. In this paper we attempt to synthesize film grain based upon the established photographic grain metric of the noise power spectrum.

1. Modeling Film Grain

The most widely used measure of film grain is Selwyn Granularity [Sel35]. This is defined as:

$$G = \sigma_D \sqrt{A} \propto \sqrt{D}$$

where D is the density, and σ_D is the standard deviation of density measured with aperture A . That G is theoretically independent of A for large apertures is only approximately true for real films. Selwyn Granularity has previously been used to simulate film grain [GM97]. However, though a good measure of the average noise level, G tells us little about the actual appearance of grain.

A more powerful metric is the noise-power spectrum: W [Jon55]. Analysis [GS85] predicts that for colour-negative film W will have the form:

$$W(w) = W(0)e^{-\left(\frac{2}{9\pi}\right)^{1/3}(\pi wd)^2}$$

where w is the spatial frequency. d is the dye-cloud diameter, and $W(0) = G^2$ [Sau90].

Measurement of the noise power spectrum of real film grain shows good agreement with W . However correlation with empirical data can be improved using two values of d — one representing the diameter of a single dye-cloud, the other representing a typical dye-cloud cluster. These can be adjusted to match specific coatings. Here we use the values of $6.5\mu\text{m}$ and $15\mu\text{m}$. The two spectra are simply averaged

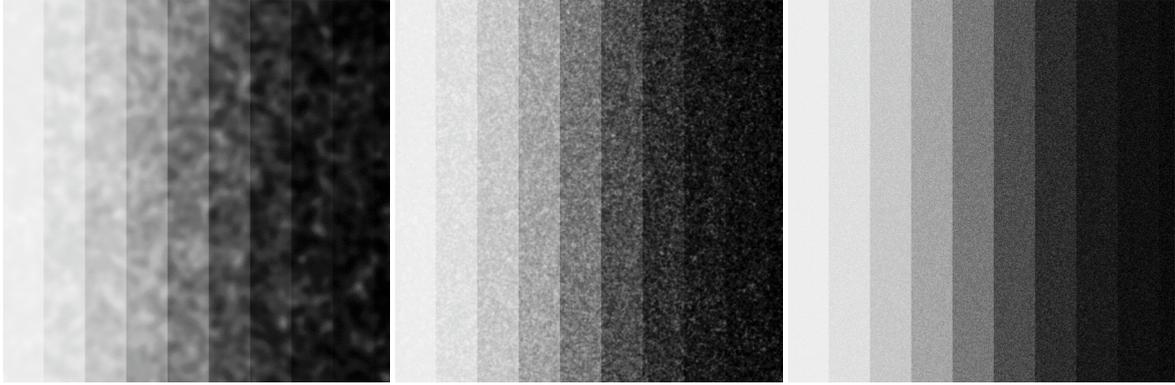


Figure 1: Simulated negatives of width 0.2mm, 1mm and 5mm

to produce a spectrum which better matches that of real film:

$$W'(w) = \frac{1}{2}W_{d=6.5\mu m}(w) + \frac{1}{2}W_{d=15\mu m}(w)$$

2. Implementation

To synthesize film grain we note that $W(w)$ can be decomposed into $W(0)$, which is simply a scale factor, and the remaining part which is independent of negative density. We therefore generate a grain pattern without reference to a particular image, and then combine the image and grain in a second step.

2.1. Grain Field Generation

To create noise with the correct spectral characteristics we first generate white noise. This can be Fourier transformed [FMJS05] into frequency space where it is filtered according to $W(w)/W(0)$. The resulting noise is then transformed back to the spatial domain to obtain a grain value g for each pixel.

While in principle this is simple, a number of pitfalls must be avoided to ensure consistent results when different enlargements are simulated. Pixel coordinates in the transformed image represent cycles (or in photographic terms lines) per negative, which must be divided by the width of the simulated negative n to convert this to lines per mm which can be used in the filter function. More subtly the resolution of the simulation must be taken into account — simulating at a higher resolution should not affect the results. The highest frequency that can be simulated is approximately:

$$f = 0.5r/n$$

where r is the linear resolution of the sampled image. Scaling the noise by f ensures that the simulation is resolution independent.

The DC component of the signal is removed, so grain does not affect the average density.

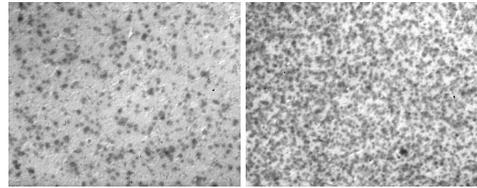


Figure 2: Real Film Grain

2.2. Tone Mapping

Having synthesized noise, it must now be incorporated into the rendered image. The values recorded in a rendered image represent the light hitting the image plane, though they may have been gamma corrected, in which case they must be transformed back to a linear form. These light values can then be used as the basis for a simulated exposure.

Though the response of a real negative is complex [Ada95], for the purposes of simulating grain, the density of an exposed negative to can be approximated by:

$$D = \frac{D_{max}}{1 + e^{4\gamma(z_i - z)}}$$

where z is the log exposure, and z_i is the exposure which corresponds to $\frac{1}{2}D_{max}$ [Sau93]. As g must still be scaled by $W(0)$, and $W(0) \propto D$, the light intensity transmitted through the negative with grain incorporated, (and the value recorded in the output image) is:

$$i \propto 10^{-D(1+kg)}$$

k is simply a scale factor setting the overall amplitude of the grain.

3. Results

The image in figure 1 shows virtual negatives produced by a step wedge exposure at a range of enlargements. The grain

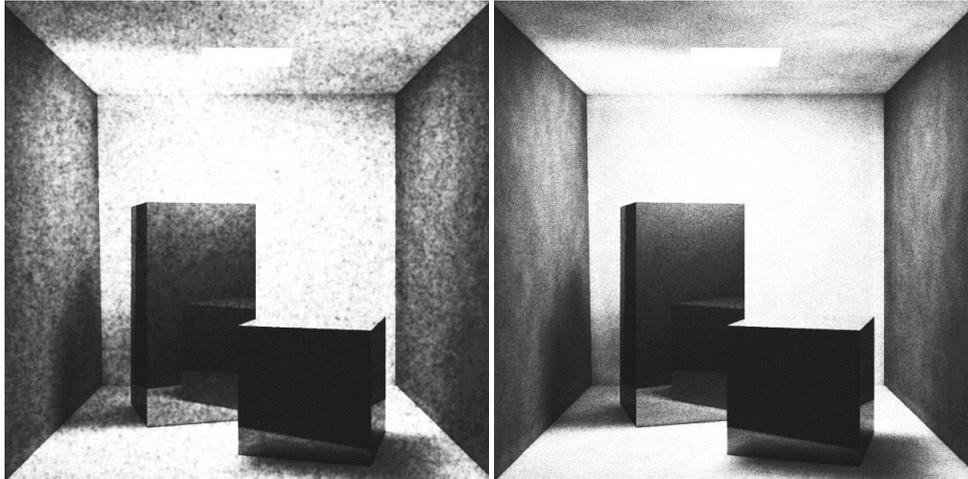


Figure 3: *Simulated Positive prints: Negative Sizes 1mm and 5mm*

scales correctly as the resolution, and size of the virtual negative changes. Visual comparison to the real film grain in figure 2 shows that at moderate enlargements (where the grain pattern is clearly visible, but individual grains are not prominent) the simulated grain is a good approximation to real film grain.

Ideally some form of formal comparison would be performed between the simulated and real film grain, providing an objective metric for the accuracy of the simulation. However the two standard measures of film grain, Selwyn granularity and noise power spectra have been used to *produce* the simulated grain — as such any measurement of the simulated grain will indicate that it is a match to real grain. The visual differences between real and simulated noise are a product of some feature not captured by current film grain metrics.

At the highest enlargements (where individual grains become visible) the simulation becomes less convincing. The simulation cannot realistically form individual grains as it is purely based on the spectral power. Real grains would result in a strong correlation in the phase of the spectrum which is not represented by noise power spectrum measurements of real grain, the theoretical derivation of $W(w)$ or the simulation.

In a real photographic negative, density is formed by grains, whereas the noise power-spectrum model considers grain as noise added to an average density. Individual grains do not vary in density, but rather the number of developed grains changes, in relation to the exposure, creating an average density. This is a fundamental limitation of the noise power-spectrum approach to grain synthesis, and other models which are based upon grain as additive noise. The problem is most significant at the largest magnifications where

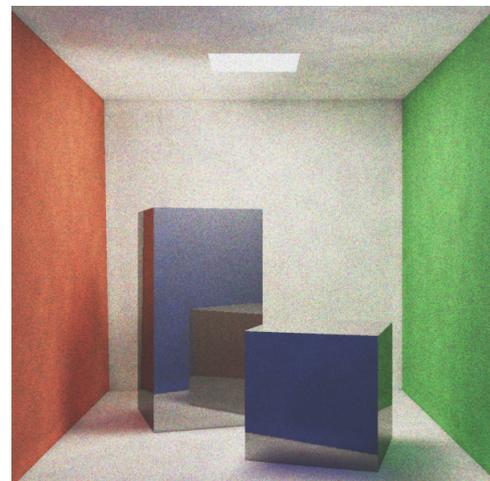


Figure 4: *A Simulated Colour Print: Negative Size 5mm*

individual grains become a noticeable feature of the overall image.

Figure 3 shows the results of the process on a rendered image. In order to produce a positive “print” the negative with grain included must be re-exposed to calculate the print’s reflective density and the amount of light reflected from the surface. Though the printing paper itself adds grain it is not optically enlarged as the film grain is, and hence does not contribute to the final image.

The effect of simulated grain on a colour image is shown in figure 4. We assume that the formation of grain in each layer is independent, and add simulated grain to each colour channel separately. The dye cloud, and cluster diameters

used are the same for each layer, though this need not be the case.

4. Conclusions

These results both verify, and show the limitations of noise power spectra for use in the simulation of film grain, and in its original sensitometric application as a measure of film grain. The images have the correct statistical properties and are convincing at small and intermediate magnifications.

The results are less convincing at the highest magnifications where individual grains become visible. Though an improvement over Granularity, power spectra do not fully capture the characteristics of film grain, and hence have only limited predictive power, as they do not include phase information which could lead to the formation of individual grains. Grain patterns may have very similar noise spectra but different appearance due to this uncontrolled parameter.

Like most photographic models of grain, power spectra models grain as additive noise on top of a perfect image, when in fact the grains form the image. More advanced models are required which consider the image formation process directly.

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